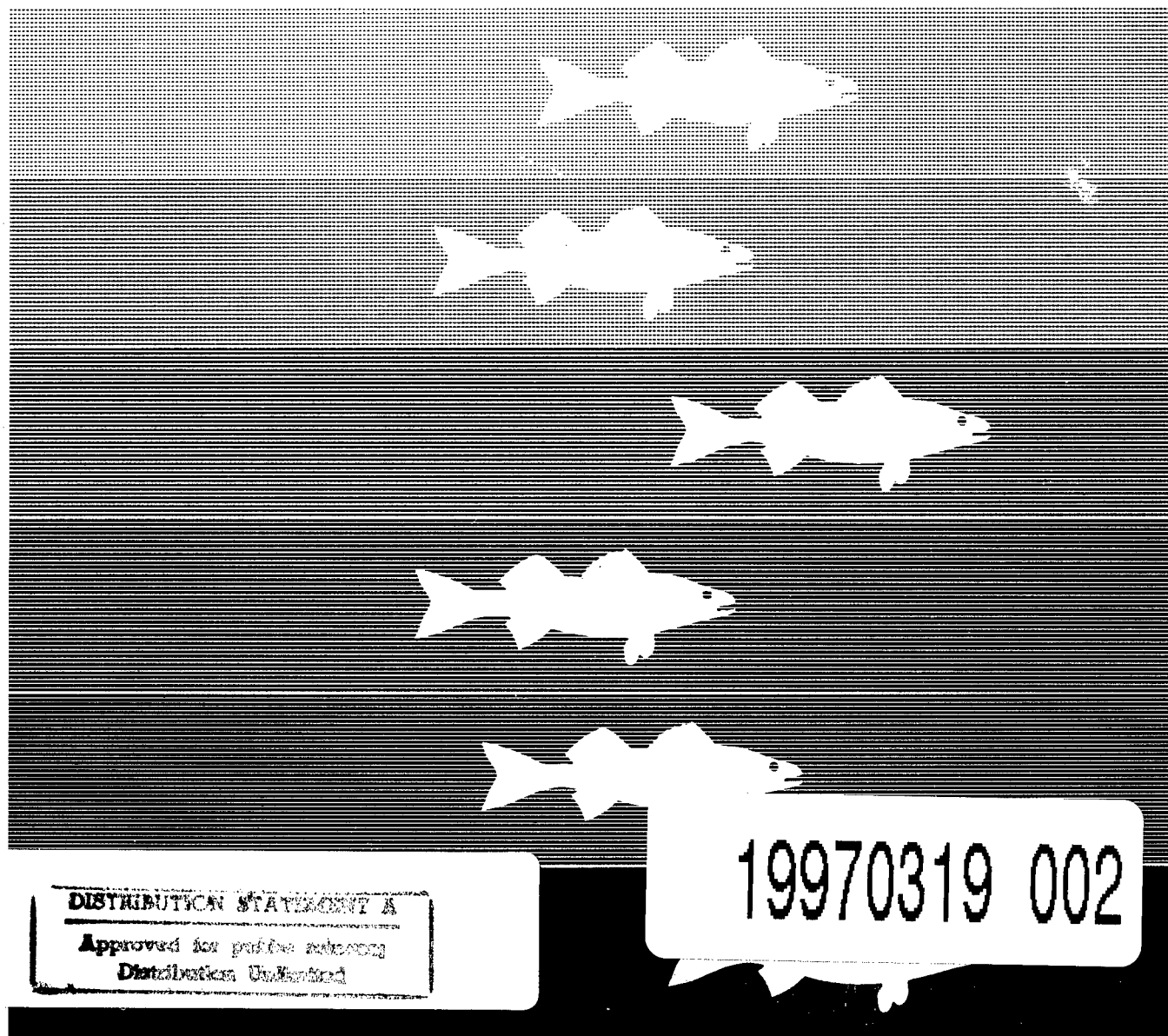


# Limnological and Fishery Studies on Lake Sharpe, a Main-stem Missouri River Reservoir, 1964-1975



UNITED STATES DEPARTMENT OF THE INTERIOR  
FISH AND WILDLIFE SERVICE  
*Fish and Wildlife Technical Report 8*

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# **Limnological and Fishery Studies on Lake Sharpe, a Main-stem Missouri River Reservoir, 1964-1975**

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Gerald K. O'Bryan  
David A. Vogel



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## Preface

This compilation of papers records the results of studies carried out on Lake Sharpe, an upper Missouri River reservoir in central South Dakota, during the early years of impoundment. The work was conducted in 1965-75 by the Pierre (South Dakota) Biological Station of North Central Reservoir Investigations, National Reservoir Research Program, U.S. Fish and Wildlife Service.

The overall aim of these studies was to determine the ecological effects of impoundment and subsequent water management in this flow-through reservoir. Initial objectives were to describe the characteristics of the water and the biota; to investigate the relation between environmental changes and the biota, with particular emphasis on the fish stocks; and to provide some of the information required to enable the development of sound decisions about the use of the water and fish.

More extensive studies that were planned were not completed because the Pierre Biological Station was closed and the staff reassigned in early 1979. Nevertheless, I believe that the present reports, together with earlier published contributions, provide essential information on the development of fish stocks during the early years of impoundment. The six papers assembled here include information on the general hydrography and synoptic limnology of the reservoir; on the composition and abundance of plankton, benthos, and fish stocks; on some apparent interrelations among the fish stocks (especially young of the year) and between the fish stocks and their environment; and on the biology of three of the most important fishes—walleyes, yellow perch, and gizzard shad. It is hoped that various judgments and recommendations given here will help guide decisions about the future management of the water and fish stocks of this reservoir.

Fred C. June

# Physical, Chemical, and Biological Characteristics of Lake Sharpe, South Dakota, 1966-1975

by

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## Abstract

Lake Sharpe, the most recent of six main-stem Missouri River reservoirs to be impounded, began to fill in November 1963 and became fully operational in July 1966. At full pool it is 137 km long, and has a surface area of 22,600 ha and a volume of 2.34 km<sup>3</sup>. It is operated as a flow-through power generation system that reregulates discharges from upstream Lake Oahe. Major changes in the water-management regimen during 1966-75 were increased summer discharges beginning in 1969 and increased peaking operations beginning in 1973. Lake Sharpe had a relatively short aging process because it filled rapidly, the water level remained relatively stable, and the water-exchange rate was high. Consequently, most physical, chemical, and biological characteristics were remarkably uniform during 1966-75. The temperature regimen was largely governed by inflow from Lake Oahe. Although the water mass warmed during summer, thermal stratification was generally transient, limited to the lower reservoir, and more common during periods of relatively low discharge rates in 1966-68 than in later years. Variation in turbidity was striking; the midsection of the reservoir was generally most turbid. Chemical ion composition of the water tended to be uniform; observed differences were localized and associated with tributary inflows. Phytoplankton abundance reached its highest levels during 1970-75. Composition of the zooplankton community changed during 1966-75; the abundance of cyclopoid copepods decreased and that of calanoid copepods and cladocerans increased. Total abundance varied during the 10-year period, but without apparent trend. Variation in abundance appeared to be associated with discharge rate, water temperature, and turbidity. The benthic community in 1967-68 consisted mostly of chironomid larvae, which were uniformly distributed over the length of the reservoir.

Selected physical and chemical characteristics of Lake Sharpe and the compositions and standing crops of the plankton (1966-75) and the benthos (1967-68) are described for the open-water months of April to October. The purpose of the study was to provide an overview of the limnology of the reservoir from which relations between changes in environmental conditions and the fish stock might be deduced.

Five reports dealing with the limnology of Lake Sharpe have previously appeared. Fogle (1965) examined some chemical and physical components

during 1964 to determine the suitability of the reservoir for stocking with rainbow trout (*Salmo gairdneri*); Grover (1969) examined the populations of benthic invertebrates during 1967-68 in his reevaluation of the reservoir for possible introduction of coldwater fish species; Rada (1970) studied the limnetic zooplankton and phytoplankton during 1966-68; Martin et al. (1980) studied plankton community metabolism and related physicochemical characteristics during 1971-72; and Martin (1980) detailed predictive regressions for determining gross primary production and community respiration on the basis of data collected in 1971-72.

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## Description of the Reservoir

Lake Sharpe, the last of six main-stem reservoirs completed on the Missouri River, was formed by Big Bend Dam, located at Fort Thompson, South Dakota (Fig. 1). Filling of the reservoir began in November 1963, and water was first released through the power generating units in October 1964. The reservoir became fully operational in July 1966 and thereafter functioned as a main-stream power generation system that reregulates releases from Oahe Dam. The reservoir has a surface area of 22,600 ha and a volume of 2.34 km<sup>3</sup>. It lies in the Great Plains physiographic province and separates the glaciated "Coteau du Missouri" division on the east bank from the unglaciated Pierre Hills section on the west bank. Petsch (1946) and Rothrock (1943, 1944) detailed the regional geology. Three intermittent streams—Medicine Knoll, Chapelle, and Joe creeks—constitute the major drainages on the east bank, and five intermittent streams—the Bad River and Antelope, Cedar, Medicine, and Counselor creeks—form the

major drainages on the west bank. The Bad River, the major tributary of Lake Sharpe (even though intermittent), drains the Badlands of South Dakota and enters the reservoir at Fort Pierre. Inflow into the reservoir from the Bad River and other tributaries is insignificant compared with that from Lake Oahe.

Lake Sharpe follows a serpentine course of 137 km between Oahe Dam and Big Bend Dam; its most distinctive morphological feature is the "big bend" near its lower end. Two large wooded islands—LeFramboise and Farm—and several brush-covered islets are in the upper reservoir. Hipple Lake is the only significant backwater area; it is about 5 km long and has a maximum width and depth of about 0.7 km and 4 m. Other selected morphological features of Lake Sharpe follow: shoreline length, 332 km (including the upper river portion); shoreline development, 6.1; mean and maximum depths, 10.4 and 25.5 m (off Counselor Creek); mean width, 1.6 km; annual mean sediment inflow, 5.4 million m<sup>3</sup>; volume development, 1.2; and slope of basin, 14%.

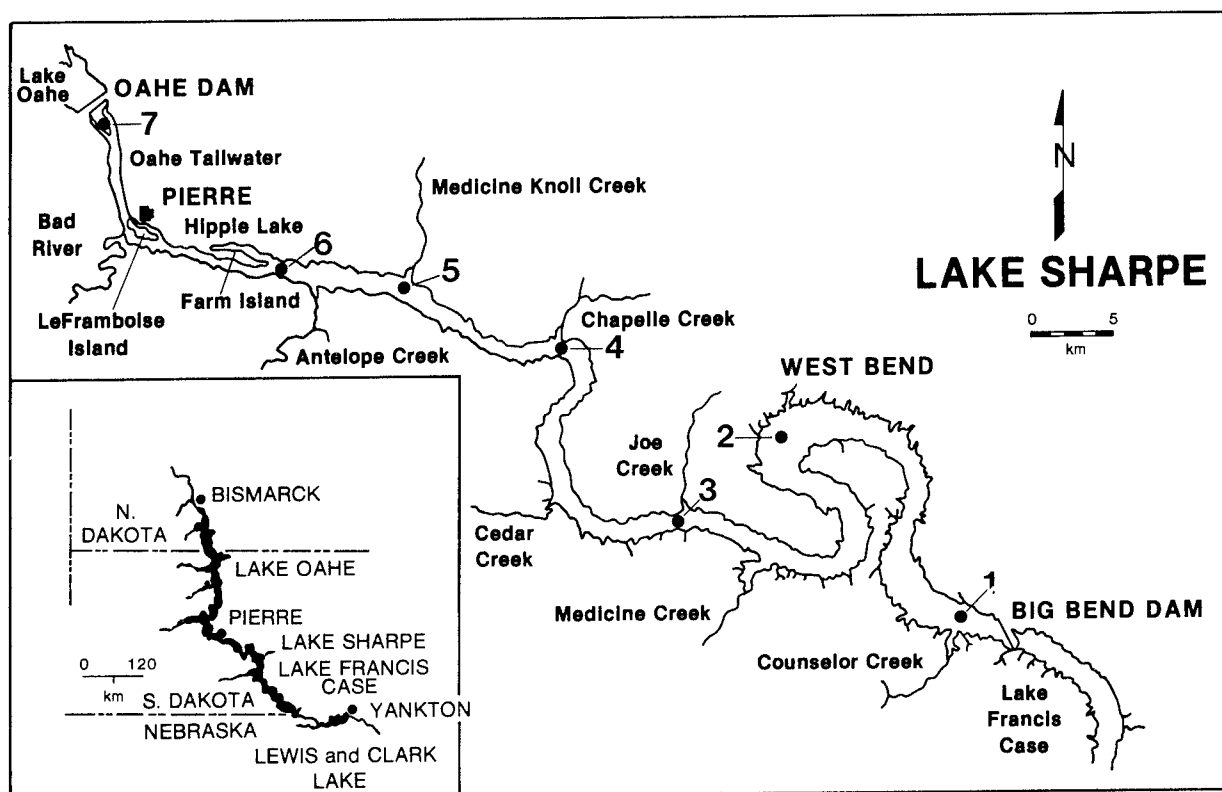


Fig. 1. Location of sampling stations in Lake Sharpe (1-7 and Hipple Lake, near station 6).

The reservoir bottom is generally flat as a result of sedimentation and current action after impoundment. Bottom composition varies with location and is most diverse in the upper 20 km of the reservoir. The bottom consists of bank gravel in the tailrace area, and changes to sand (particle size  $< 6$  mm) within the first several kilometers downstream. Backwaters in the upper reach have a mud bottom (materials that pass through a No. 60 soil screen). The bottom between Medicine Knoll and Chapelle creeks (stations 4 and 5, Fig. 1) consists mostly of light chalky-brown mud originating from the Bad River. Dark gray muds predominate downstream.

The regional climate is semiarid. Annual precipitation averages about 44 cm, more than half of which falls as rain or snow during spring. Air temperatures range from about  $-36$  to  $47^{\circ}\text{C}$  and average  $8^{\circ}\text{C}$  annually (data courtesy of National Oceanic and Atmospheric Administration, Environmental Data Service, Asheville, North Carolina). Air temperatures are usually lowest in January or February (mean about  $-9^{\circ}\text{C}$ ), and highest in July (mean about  $26^{\circ}\text{C}$ ). The lower two-thirds of the reservoir and all tributary embayments and backwater areas are covered with thick ice from December to March or April. Total annual radiation exceeds  $1.3 \times 10^5$  kcal/m<sup>2</sup>.

Surface wind is an important weather factor affecting Lake Sharpe. Prevailing winds are east-southeast from May to September and northwesterly from October to April. The annual mean wind speed is 18 km/h, and the range of the monthly means is 16.3–21.5 km/h. Wind-generated waves often break with great force on the exposed reservoir banks and shorelines and cause shoreline erosion and massive slumping. Most of the reservoir shoreline is exposed to wave action that precludes the establishment of emergent aquatic vegetation, except in a few protected backwater areas.

Land bordering the reservoir is used primarily for livestock grazing. Some of it is cultivated, and the acreage brought under irrigation greatly increased during 1970–75.

Lake Sharpe reached the operating elevation of 432.8 m above mean sea level (msl) on 5 December 1965. The water level remained relatively stable, except on occasions when it was lowered to accommodate flood flows from the Bad River or when power demands were unusually heavy.

Annual fluctuations in water level during 1966–75 averaged only 79 cm.

Water is discharged into Lake Sharpe from Lake Oahe. The amounts of water withdrawn through the intake openings (490 m above msl) from different levels of the vertical water column at Oahe Dam are unknown. However, it appears that under usual operational conditions most of the water discharged from Lake Oahe is from the metalimnion and the upper hypolimnion (June 1974).

Water discharged from Lake Sharpe passes through eight Kaplan (fixed-blade) turbines from the forebay area, which is about 213 m wide and 24 m deep. Water can be drawn from the full depth; however, observations by Wunderlich (1971) indicated that it may be taken disproportionately from the various layers in the water column.

There were several major changes in the annual water-discharge regimen after the reservoir became fully operational in 1966. During 1966–68, daily discharge rate reached a peak of 1,413 m<sup>3</sup>/s and averaged 640 m<sup>3</sup>/s; annual outflow volume averaged 20.2 km<sup>3</sup>; and estimated mean flushing time was about 40 days (Table 1). Beginning in 1969, the discharge rate increased, particularly during summer, and flushing time dropped to 34 days. The discharge rate continued to increase during the next 2 years and reached an initial peak in 1971, when flushing time was reduced to 27 days. Another major change in the discharge regimen occurred in 1973, when peaking operations (variations in discharge rates in relation to power demands during a 24-h period) increased, and the number of weekend days on which there was no discharge increased fourfold, to 24 days. Discharge rates and flow volumes reached a maximum in 1975.

In most years, discharges increased at the beginning of the open-water period (April) and usually peaked in summer; in 1975, however, maximum outflow was in October due to flood control operation.

## Materials and Methods

Seven reservoir sampling stations were established in 1966 (Fig. 1; Table 2). Station 1 was 6 km upstream from Big Bend Dam; stations 2 to 6 were

Table 1. *Annual flow volumes, daily discharge rates, and calculated flushing times, Lake Sharpe 1966-75.*<sup>a</sup>

Year	Volume (km <sup>3</sup> )		Discharge rate (m <sup>3</sup> /s)			Flushing time (days)
	Inflow	Outflow	Range	Mean	SE	
1966	19.81	19.56	82-1,252	620	11.8	42.4
1967	19.57	19.34	0-1,413	613	13.2	41.3
1968	21.94	21.74	0-1,405	688	14.1	37.6
1969	24.93	25.19	85-1,846	791	17.3	33.8
1970	26.24	25.96	0-1,753	823	17.8	31.2
1971	31.26	31.00	0-1,745	983	19.6	27.4
1972	29.66	29.44	0-1,844	931	20.5	27.8
1973	18.90	18.62	0-1,671	591	17.9	46.0
1974	22.31	22.09	0-1,583	701	20.8	37.2
1975	33.06	32.83	0-1,960	1,041	26.8	27.8

<sup>a</sup>Source: U.S. Army Corps of Engineers, Omaha District.

at locations where there was a major change in water depth or one of the larger tributaries entered the reservoir; and station 7 was in Oahe Dam tailwater.

Water samples and field measurements were taken monthly from April to October 1966-75 (except in April 1967, 1971, and 1972 and September 1970). Stations were occupied in a downstream sequence from 7 to 1, and each sampling cruise was completed in 1 to 1-1/2 days.

Water samples were collected with a 2-L Van Dorn sampler. Samples were initially taken 1 m below the surface, at middepth, and 1 m above the bottom; however, because of the relative homogeneity of the water mass from surface to bottom, middepth samples were discontinued at stations 4-7 after 1966.

Temperature, dissolved oxygen concentration, and specific conductance were determined aboard the vessel. Temperature and oxygen measurements were made with a Precision Scientific Instruments Galvanic Cell Oxygen Analyzer. Temperature readings, which were calibrated against a National Bureau of Standards certified mercury thermometer, were accurate within  $\pm 0.1^\circ\text{C}$ . Sub-surface temperatures at stations 1-3 were also measured with a bathythermograph. Oxygen readings were calibrated against the azide modification of the Winkler method (American Public Health Association et al. 1960). Specific conductance ( $\mu\text{mho/cm}$  at  $25^\circ\text{C}$ ) was determined with an Industrial Instruments RB2 Solu Bridge.

Turbidity of a 100-mL subsample drawn from each water sample was measured either aboard the vessel or in the laboratory with a Hach Turbidimeter and reported in Jackson Turbidity Units (JTU).

Transmissivity of the water, in percent, was determined at 1-m intervals from surface to bottom with a Hydro Products Transmissometer System composed of a deck readout unit and 10-cm sensor.

Phytoplankton samples were collected 1 m below the surface at each station with a 1-L Van Dorn water bottle and preserved with 5% buffered

Table 2. *Locations and mean depths of sampling stations, Lake Sharpe.*

Station <sup>a</sup>	Location	Distance upstream from Big Bend Dam (km)	Mean depth (m)
	Geographical designation		
1	Counselor Creek	6	23.0
2	West Bend	35	17.4
3	Joe Creek	60	14.0
4	Chapelle Creek	89	6.4
5	Medicine Knoll Creek	101	5.8
6	Farm Island	108	5.8
7	Oahe tailwater	137	5.4

<sup>a</sup>See Fig. 1 for locations of stations.

formalin. The 1966-69 samples were processed by agitating and withdrawing two 1-mL subsamples with an automatic pipette. Subsamples were allowed to stand in small petri dishes for about 24 h before the plankton was counted. Organisms in 30 randomly chosen fields were examined at  $\times 100$  and  $\times 200$ , identified to genus, and counted. The 1970-75 samples were concentrated with a Foerst centrifuge, and the numbers of cells per liter were estimated from strip sample counts in a Sedgwick-Rafter counting cell, following the method described by American Public Health Association et al. (1971). Because of these differences in technique, I did not combine phytoplankton counts for 1966-69 and 1970-75 for analysis.

The zooplankton standing stock was sampled at each station with a Miller sampler (Miller 1961) equipped with a TSK flowmeter and a No. 10 nylon net (0.153-mm mesh) having an attached bucket. The sampler was lowered to 1 m above the bottom and, with the vessel under way, raised at the rate of about 1.3 m/min during each tow. A standardized 5-min tow was made at stations 4-7; tows at other stations ranged from 10 to 18 min, depending on water depth. A relatively uniform sampling speed was maintained during each tow by adjusting engine speed to control the wire angle. At the end of a tow, captured organisms were washed into the plankton bucket, transferred to a glass bottle, and preserved with 5% buffered formalin.

The number of organisms in each sample was determined according to the method described by June (1974), and the ash-free dry weight was determined for available samples as described for periphyton by American Public Health Association et al. (1971). Samples were randomly chosen for species identifications each year, but routine counts were made only to genus. Nauplii were included in the total counts, but not in the composition analyses. Counts are reported as number per liter.

Three special investigations were also conducted. The first, an aerial determination of surface-water temperatures, was made with an infrared radiation thermometer in 1966 under a contract with the Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City. Flights were made at about monthly intervals from late April to late October. Time required for flights on a median course over

the reservoir ranged from 38 to 48 min. The temperature readings by infrared radiation thermometry were converted to printouts at 0.5-km intervals along the flight course. Reference surface temperatures were determined with either a bucket thermometer or calibrated thermistor at one or more locations at the time of flyover.

The second study was a determination of the concentrations of 10 selected ions, along with pH, hardness, and total dissolved solids, in October 1967. The analyses were made by Dr. John Madden under a contract with the Water Resources Research Institute, South Dakota State University, Brookings.

The third investigation was of the benthos community, which was sampled along six reservoir transects from June 1967 to August 1968 (Grover 1969). Five of the transects were in the immediate vicinity of the established sampling stations; the sixth was about midway between stations 5 and 6. Samples were also taken in the Hipple Lake backwater. Two to eight samples per transect, stratified according to depth and reservoir width, were collected biweekly during the open-water period and, when conditions permitted, during winter. Supplemental sampling was conducted at random in diverse habitats throughout the reservoir. Samples were taken with a No. 1 orange-peel dredge (inside diameter 26 cm; maximum sampling area 0.053 m<sup>2</sup>). Individual samples were sieved through a No. 60 soil screen (0.25-mm openings) and preserved in 10% formalin. Benthic organisms were separated from the mud and detritus by sugar flotation (Anderson 1959), identified to major taxonomic groups, and reported in numbers of organisms per square meter.

Further data on water levels and discharge rates, as well as on temperature, specific conductance, dissolved oxygen, and other chemical features of the inflow and outflow from Oahe and Big Bend dams, were provided by the Omaha District, U.S. Army Corps of Engineers.

## Physical Characteristics of Lake Sharpe

Measurements of the surface water temperature in 1966 by infrared radiation thermometry showed

Table 3. *Mean surface water temperatures as determined by infrared radiation thermometry on different dates, Lake Sharpe, 1966.*

Date	Range (°C)	Mean (°C)
25 April	4.8-5.3	5.1
25 May	6.7-11.1	9.5
29 June	14.4-19.6	16.8
20 July	17.4-24.4	21.3
29 August	17.8-22.9	20.6
4 October	12.9-20.9	15.2
27 October	10.8-13.4	11.7

little variation over the 137-km midreservoir flight path in late October (Table 3); the difference between the maximum and minimum temperatures during flyovers was 0.5 °C in April and 2.6 °C in October. The water was coldest near station 1 in April, but the gradient was reversed by late May, when the water was coldest at station 7. This late-May pattern persisted until late October, when the temperature gradient was again reversed. The gradient was most variable in August, although the temperature difference was greatest (8.0 °C) in early October. The observed pattern was due to the influence of the metalimnetic water released from Oahe Reservoir (at station 7) and seasonal atmospheric heating and cooling (at station 1).

Warming of the surface water was most rapid from May to June, when the temperature doubled at all stations, and a maximum temperature of 24.4 °C was reached in the lower reservoir in the vicinity of station 2 in July. By late October the surface temperature range was similar to that in May. The mean daily warming rate was estimated to be 0.15 °C in April and May and 0.21 °C from May to July. Daily cooling rates were 0.02 °C in July and August and 0.15 °C from August to late October.

The thermal structure in Lake Sharpe at any given time was influenced by water-exchange rate. During 1966-75, the annual mean temperature of the outflow from Lake Sharpe was higher than that of the inflow from Lake Oahe (Table 4), and temperature differences were most marked during the open-water period (April-October).

A plot of the 10-year (1966-75) mean monthly inflow and outflow temperatures (Fig. 2) showed that the outflow was generally cooler than the inflow from November through March. Rapid warming of both inflow and outflow began in April and continued until August. Rapid cooling occurred in October. The water at stations 6 and 7 was isothermous from surface to bottom throughout the open-water period, and its temperature closely followed that of the inflow.

The mean subsurface temperature, calculated from thermograms collected at station 1, was

Table 4. *Annual and seasonal (April-October) mean temperatures, and maximum temperatures, of inflow (Oahe Dam tailwater) and outflow (Big Bend Dam tailwater), Lake Sharpe, 1966-75.<sup>a</sup>*

Year	Inflow temperature (°C)				Outflow temperature (°C)			
	Annual mean	Seasonal mean	Maximum		Annual mean	Seasonal mean	Maximum	
			Reading	Date attained			Reading	Date attained
1966	9.2	12.9	23.6	18 July	9.3	14.4	23.9	30 July
1967	9.0	12.4	23.9	6 August	9.3	14.4	22.2	4 August
1968	9.8	13.3	23.0	1 August	10.0	15.1	22.6	31 July
1969	9.0	12.1	20.6	16 September	11.0	16.7	25.2	9 August
1970	9.2	12.6	21.8	9 September	10.1	15.4	23.4	15 July
1971	9.7	13.4	22.5	25 August	9.3	14.5	21.1	13 August
1972	8.2	12.0	20.6	23 August	8.4	13.6	22.2	22 August
1973	8.6	12.1	17.8	21 July	9.6	15.2	22.8	11 August
1974	8.7	12.3	20.0	4 August	9.4	14.6	23.4	26 July
1975	8.8	12.7	21.7	23 August	9.6	14.4	22.8	8 July
Mean	9.0	12.6	21.6		9.6	14.9	23.0	

<sup>a</sup>Source: U.S. Army Corps of Engineers, Omaha District.

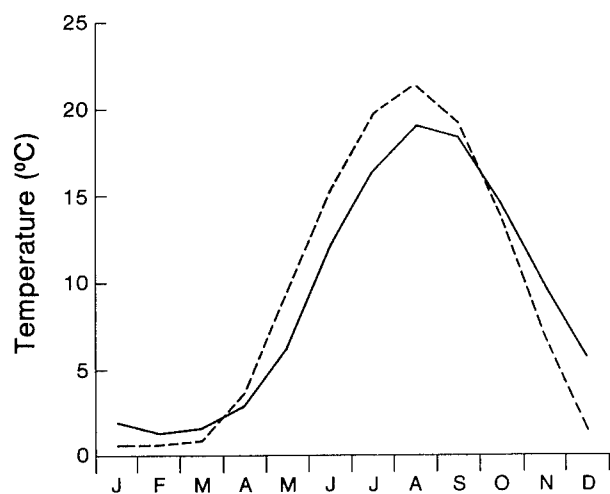


Fig. 2. Monthly mean temperature of inflow (Oahe Dam tailwater—solid line) and outflow (Big Bend Dam tailwater—broken line), Lake Sharpe, 1966–75.

highly correlated with the corresponding monthly mean outflow temperature at Big Bend Dam ( $r = 0.92$ ;  $P \leq 0.01$ ). Correlation between the daily mean outflow temperature and the mean thermogram temperature at station 1 on the cruise dates was  $r = 0.98$  ( $P < 0.01$ ), and the estimator equation was  $y = 0.96X + 0.72$ . Thus the outflow temperature provided a good estimate of the mean subsurface water temperature in the lower reservoir and indicated proportionate withdrawal from the entire water column at the dam face.

Thermal stratification of Lake Sharpe was weak, short-lived, and usually limited to station 1. Traces of stratification more commonly appeared during 1966–68 than during 1969–75. (There was no evidence of stratification in 1971–73.) The variable thermal stratification in Lake Sharpe resulted

from large inflow volumes from Lake Oahe, short water-retention times, and persistently strong winds in the region.

Variable turbidity was one of the most distinctive physical characteristics of Lake Sharpe. During the open-water period, highly turbid water often extended throughout much of the reservoir as a result of wave action on the shoreline; however, turbidity was generally lowest upstream, increased to a maximum in midreservoir, and decreased downstream (Table 5). Average near-surface turbidity readings at stations 4 and 5 were roughly fivefold to sevenfold greater than those at stations 7 or 1. The reduction in turbidity at station 1 probably resulted from the settling of silt as the current velocity became reduced in the widened lower portion of the reservoir. Readings near bottom were usually higher than those near the surface, but the latitudinal patterns of the means at both depths were similar. Middepth readings also averaged higher than those near the surface at stations 1–3; at the other stations, mid-depth and near-surface readings were usually the same.

There were marked variations in the annual mean turbidity during 1966–75; however, no significant trend over time was indicated. Except in 1975, changes in the mean turbidity of near-surface and bottom waters were similar. Turbidity tended to be higher in April than in other months (Fig. 3), due to strong winds and heavy runoff. Mean turbidity at individual stations also varied annually, but no significant trend was detected during the 10-year period. The three highest readings at station 6 (175 JTU on 23 April 1968, 76 on 23 April 1974, and 75 on 23 April 1970) were associated with high inflows from the Bad River.

Table 5. Mean turbidity (JTU) at 1 m, middepth, and 1 m above the bottom, Lake Sharpe, 1966–75.

Station <sup>a</sup>	1 m			Middepth <sup>b</sup>			Bottom		
	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE
1	1.6–10.0	4.30	0.321	2.0–18.4	6.06	0.393	1.4–35.0	11.97	1.076
2	2.5–13.0	5.96	0.430	2.7–17.8	8.26	0.712	3.6–23.0	11.48	0.762
3	2.6–20.0	9.26	0.650	3.4–23.0	11.88	0.895	4.0–29.0	14.22	0.706
4	6.6–72.5	19.60	1.315	—	—	—	7.1–71.0	23.25	1.152
5	2.8–70.0	17.43	1.579	—	—	—	3.2–83.0	21.22	1.770
6	1.8–175.0	12.14	2.695	—	—	—	1.9–170.0	13.73	2.736
7	1.1–8.8	2.86	0.199	—	—	—	1.1–20.0	4.39	0.850

<sup>a</sup>See Fig. 1 for locations of stations.

<sup>b</sup>Middepth determinations were not made at stations 4–7.

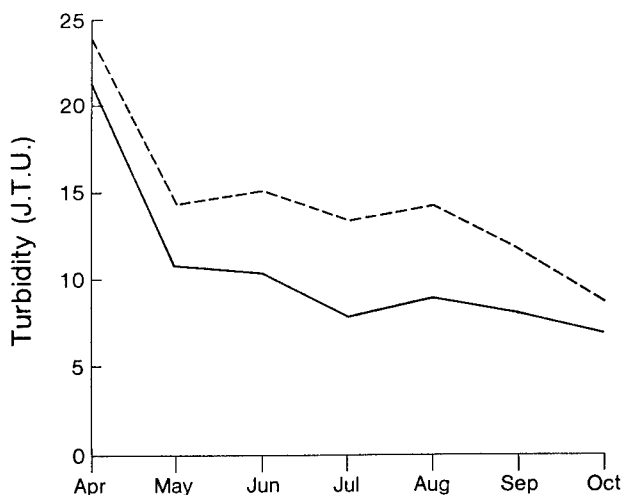


Fig. 3. Monthly mean turbidity (April-October) 1 m below surface (solid line) and 1 m above bottom (broken line), Lake Sharpe, 1966-75.

Highly turbid inflows from the Bad River were also usually evident at stations 4 and 5.

Transmissivity of the water varied greatly throughout the reservoir, and was more closely related to turbidity than to phytoplankton standing crop. There was a highly significant inverse relation between transmissivity and turbidity ( $r = -0.70$ ;  $P < 0.01$ ) and a positive relation between transmissivity and Secchi disk transparency ( $r = 0.93$ ;  $P < 0.01$ ). The correlation between transmissivity and phytoplankton was low, although significant ( $r = 0.13$ ;  $P < 0.05$ ).

Inflow from Lake Oahe at station 7 was relatively clear throughout the open-water period (Fig. 4). Transmissivity usually became greatly reduced as the water moved downstream, was lowest at station 4, and increased farther downstream as the reservoir widened and deepened. The grand means for all depths showed the same trends, although the mean transmissivity of near-bottom water diverged slightly, beginning at station 6, and the greatest difference between the near-bottom and near-surface or middepth means was at station 1. Transmissivity at all depths was most variable at stations 4-6; the standard errors of the grand means for these three stations were 3 to 5 times greater than those for the other stations. A seasonal pattern of variation in transmissivity was evident at all stations, and the grand means for both near-surface and middepth waters showed similar trends. Transmissivity generally rose from

a low in April to a maximum in June or July, decreased noticeably in September, and rose again in October.

During periods of sustained high winds, a plume of low-transparency near-surface water originating along the west shore often overlaid high-transparency water, and this phenomenon sometimes extended across the entire reservoir. Vertical transmissometer readings occasionally showed a high-turbidity zone between zones of clearer water.

Although year-to-year variations in the transmissivity of the water in Lake Sharpe were great during 1966-75, there was no overall increase in transmissivity with time, such as that noted by June (1974) in upstream Lake Oahe.

## Chemical Characteristics of Lake Sharpe

The major ionic constituents of Lake Sharpe water were sodium, calcium, magnesium, sulphates, and carbonates (Table 6). The water in October 1967 was distinctly alkaline; pH values ranged from 7.7 to 8.5 and averaged 7.9. These values were lower than those reported by Selgeby and Jones (1974) for lower Lake Oahe. The relation of the major cations differed from the usual

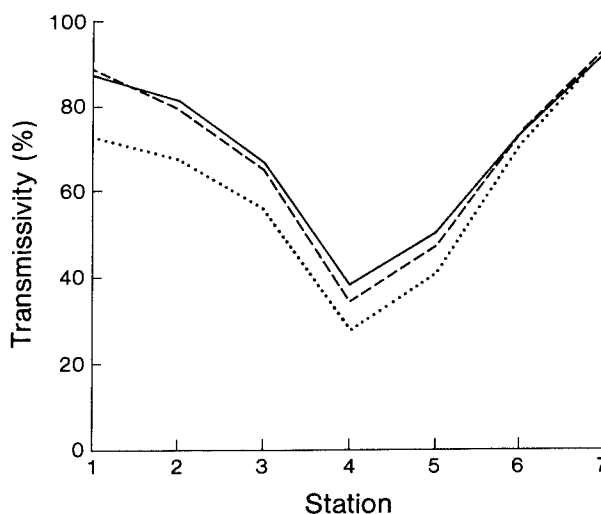


Fig. 4. Mean transmissivity 1 m below surface (solid line), at middepth (broken line), and 1 m above bottom (dotted line) at each sampling station, Lake Sharpe, 1966-75. See Fig. 1 for location of stations.

Table 6. Mean and range (mg/L) of chemical constituents of the water at stations 1-7 in October 1967, and of discharge water at Big Bend Dam, 1968-75.

Constituent <sup>a</sup>	Stations 1-7, October 1967 <sup>b</sup>		Discharge water, 1968-75 <sup>c</sup>	
	Mean	Range	Mean	Range
Calcium	66.8	56.0-76.0	57.7	56.0-60.0
Magnesium	15.4	4.8-36.0	22.1	20.0-24.0
Sodium	69.2	67.8-70.2	65.7	62.5-68.9
Iron	0.09	0.05-0.10	—	—
Potassium	4.8	4.7-5.0	4.7	3.5-5.3
Bicarbonate	—	—	186.9	178.0-195.0 <sup>d</sup>
Sulphate	168.0	145.0-195.0	211.1	108.0-274.0
Nitrate (NO <sub>3</sub> -N)	0.20	0.0-0.30	0.20	0.0-0.45
Chloride	12.0	— 12.0	8.7	1.0-14.0
Hardness <sup>e</sup>	231.0	210.0-300.0	235.0	198.0-280.0
Ammonia (NH <sub>3</sub> -N)	0.49	0.08-0.92	—	—
Total dissolved solids	462.0	322.0-548.0	—	—

<sup>a</sup>For phosphate (PO<sub>4</sub>-P), not shown, the means and ranges were 0.0009 (0.0005-0.001) for stations 1-7 and 0.021 (0.0-0.04) for the discharge water.

<sup>b</sup>Mean pH was 7.9; range was 7.7-8.5. Zinc (not tabulated) was present in trace amounts (<0.05 mg/L).

<sup>c</sup>Source: U.S. Army Corps of Engineers, Omaha District.

<sup>d</sup>Data from September 1975 to May 1977.

<sup>e</sup>Hardness as CaCO<sub>3</sub>, Ca, and Mg.

temperate zone condition (Hutchinson 1957), in that the ions Na and Ca were reversed: Na > Ca > Mg > K. Sulfate was the anion in highest concentration, followed by bicarbonate.

Conductivity of Lake Sharpe water varied relatively little during 1966-75. The 10-year mean was 743  $\mu$ mho/cm, and the range during the open-water period was 640 to 890  $\mu$ mho/cm. Although conductivity at 1 m averaged about 10% higher during 1966-71 than during 1972-75 (Fig. 5), no significant long-term trend was indicated. Seasonal means at 1 m and near bottom showed the same

year-to-year variations, with no statistically significant differences in any year. The peak in 1968 was associated with heavy runoff during April-June, when average monthly rainfall in the area was 5.3 to 10.1 cm above normal. The low in 1972 was associated with reduced rainfall in the area, combined with increased release of low-conductivity water (660-725  $\mu$ mho/cm) into Lake Sharpe from Lake Oahe, particularly during September and October.

Conductivity was generally lowest upstream and highest downstream, and both near-surface and



Fig. 5. Seasonal (April-October) mean specific conductance, 1 m below surface (solid line) and 1 m above bottom (broken line), Lake Sharpe, 1966-75.

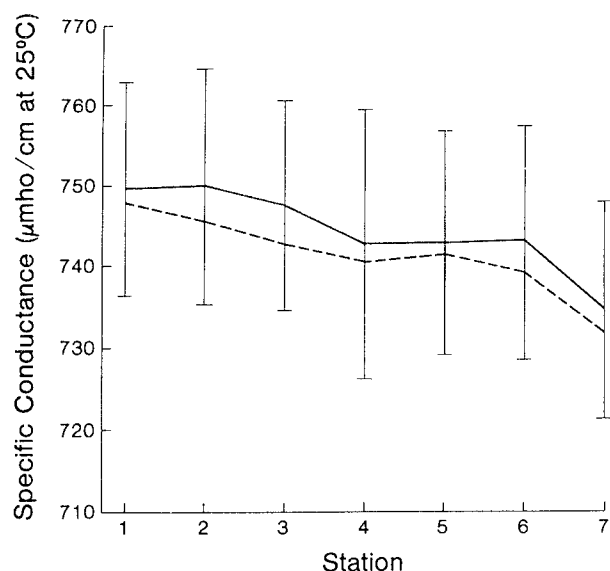


Fig. 6. Mean specific conductance at each sampling station, 1 m below surface (solid line) and 1 m above bottom (broken line), Lake Sharpe, 1966-75. Vertical lines show limits of the 0.95 fiducial interval for the mean values at 1 m below surface. See Fig. 1 for location of stations.

near-bottom means showed the same pattern (Fig. 6). Greater variability at station 4 and increased conductivity downstream were probably due to agricultural practices on lands bordering this area of the reservoir. Inflow from the Bad River, and discharges from the towns of Pierre and Fort Pierre, probably caused the abrupt increase in conductivity at station 6. In general, however,

variations in conductivity tended to be restricted by rapid passage of the water through the reservoir, normally low inflow from tributary streams, and a lack of industrial development along the reservoir.

Seasonal changes in conductivity were distinct. In most years, water of relatively high conductivity was discharged from Lake Oahe into Lake Sharpe in April and May, and seemingly overrode bottom waters of lower conductivity in the lower reservoir. Mean conductivity of the water was often significantly higher near the surface than at middepth or on bottom at stations 1-3 in April and May. In general, conductivity decreased through the summer to its annual minimum in October (Fig. 7).

Dissolved oxygen concentrations in Lake Sharpe were near saturation at all depths throughout the open-water period. Concentrations were usually highest in near-surface and middepth waters at all stations and lowest near the bottom at stations 1-3. However, near-bottom values even at stations 1-3 seldom fell below 85% saturation; the greatest range in dissolved oxygen was 4.4 mg/L (bottom) to 7.3 mg/L (surface) at station 1 on 22 July 1966. Dissolved oxygen concentrations were usually between 7.0 and 11.6 mg/L at all depths, and often exceeded 100% saturation throughout the open-water period. Even in April, soon after the ice broke up, when oxygen levels in deep water might be expected to be low, near-bottom values at stations 1-3 usually indicated supersaturation. It appears that the short water-retention times, and

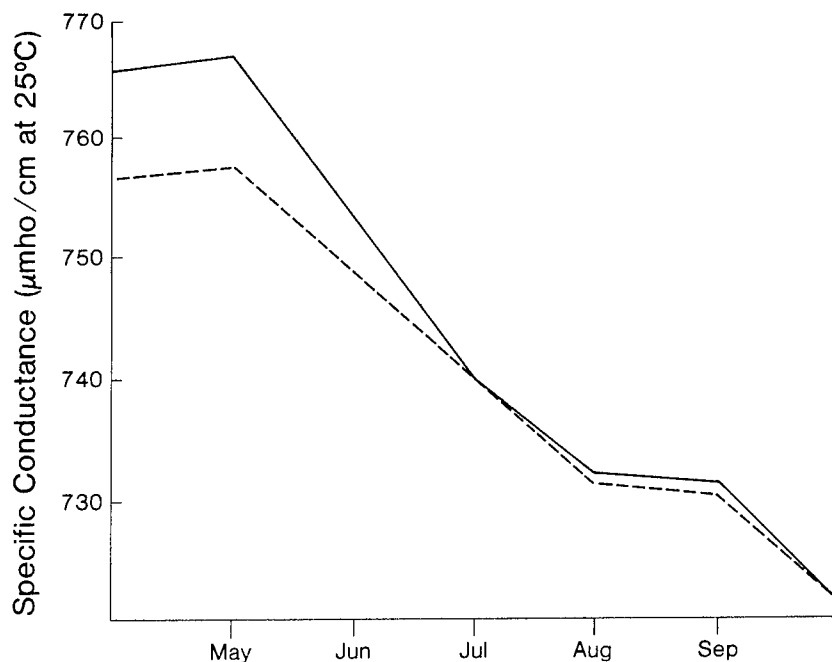


Fig. 7. Monthly mean specific conductance (April-October) 1 m below surface (solid line) and 1 m above bottom (broken line), Lake Sharpe, 1966-75.

low biological activity (Martin et al. 1980), resulted in year-round high dissolved oxygen concentrations.

## Biological Characteristics of Lake Sharpe

### *Phytoplankton*

The phytoplankton of Lake Sharpe was dominated by diatoms (Fig. 8), which accounted for 51 to 98% of the seasonal total cell numbers during 1966-75. Green algae contributed 3 to 20% of the seasonal totals during 1966-70, and Cryptophyceae accounted for 11 to 45% during 1966-69. Cryptophyceae were not counted after 1969 because long-term storage and centrifugation of samples destroyed many of the organisms. However, Martin et al. (1980) reported flagellates to be the most abundant group in Lake Sharpe during 1971-72.

The phytoplankton included 51 genera (Table 7); however, the composition changed during the

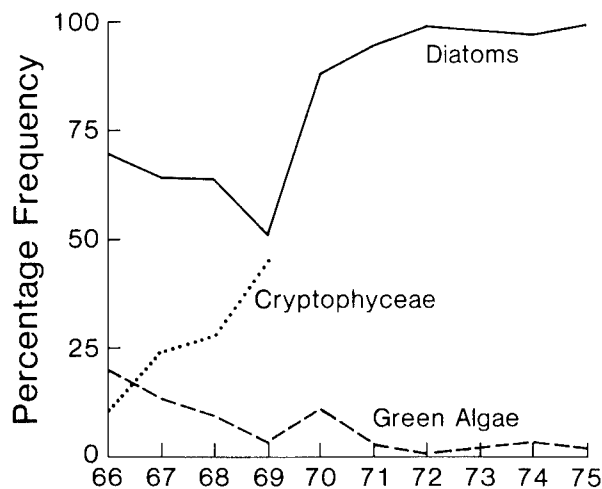


Fig. 8. Mean percentage contributions by the three major components of the phytoplankton, Lake Sharpe, 1966-75 (Cryptophyceae were not counted after 1969).

10-year period. Diatoms increased in importance after 1969, and green algae decreased, and traces of other groups appeared after 1970. Nineteen

Table 7. *Phytoplankton genera identified in samples collected in Lake Sharpe, 1966-75.*

#### Division Euglenophyta (euglenoids)

*Euglena*

*Phacus*

#### Division Chlorophyta (green algae)

*Actinastrum*

*Ankistrodesmus*

*Asterococcus*

*Chlamydomonas*

*Closterium*

*Coelastrum*

*Crucigenia*

*Dactylothece*

*Eudorina*

*Gloeocystis*

*Kirchneriella*

*Microspora*

*Netrium*

*Oocystis*

*Pandorina*

*Pediastrum*

*Scenedesmus*

*Schroederia*

*Sphaerocystis*

*Staurastrum*

#### Division Chrysophyta (yellow-green algae)

*Asterionella*

*Cyclotella*

*Cymatopleura*

*Cymbella*

*Diatoma*

*Dinobryon*

*Fragilaria*

*Gomphonema*

*Gyrosigma*

*Melosira*

*Meridion*

*Navicula*

*Nitzschia*

*Pleurosigma*

*Rhoicosphenia*

*Sirurella*

*Stephanodiscus*

*Synedra*

*Tabellaria*

#### Division Pyrrophyta (dinoflagellates)

*Ceratium*

*Peridinium*

#### Division Cyanophyta (blue-green algae)

*Anabaena*

*Anacystis*

*Aphanizomenon*

*Gomphosphaeria*

*Oscillatoria*

*Phormidium*

#### Division Cryptophyta (blue and red flagellates)

*Cryptomonas*

*Rhodomonas*

genera found in 1966-69 were not seen in 1970-75, and 21 genera found in 1970-75 were not seen in 1966-69. The five most common genera during 1966-69, in order of importance, were *Asterionella*, *Rhodomonas*, *Cryptomonas*, *Synedra*, and *Fragilaria*; these genera accounted for 80% of the 4-year total. The five dominant genera in 1970-75 were *Asterionella*, *Fragilaria*, *Melosira*, *Synedra*, and *Cyclotella*. *Asterionella*, the most abundant genus throughout the 10-year period, contributed 39 to 54% of the total.

The total mean standing crop of phytoplankton during the open-water period increased during 1970-75 (Fig. 9). Average abundance was about 5 times greater in 1974 and 1975 than in 1970. Although the mean estimated numbers for 1966-69 were not directly comparable with those for 1970-75, there was also an increase during the earlier period; mean numbers in 1969 were nearly double those in 1966.

The increase during 1966-68 was directly opposite that observed in Lake Oahe during those same years (June 1974); however, inasmuch as the two reservoirs were in different stages of development and were operated differently, their phytoplankton crops would not necessarily follow parallel trends.

Monthly mean phytoplankton densities varied greatly during 1970-75, but followed a generalized seasonal production cycle (Fig. 10): densities usually were highest in April or May (highest in June in 1970) and lowest in July or August. Mean densities during summer were about half those in

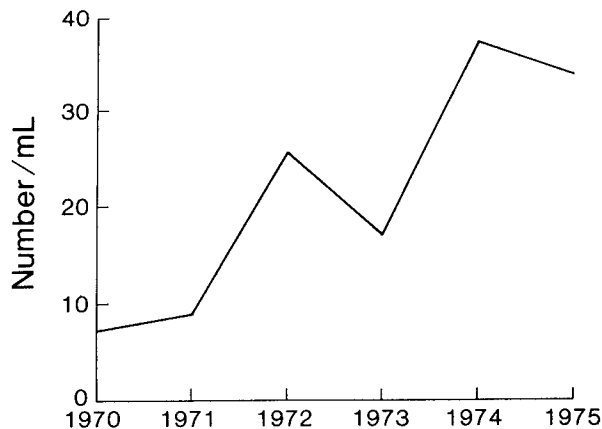


Fig. 9. Seasonal (April-October) mean phytoplankton counts, Lake Sharpe, 1970-75.

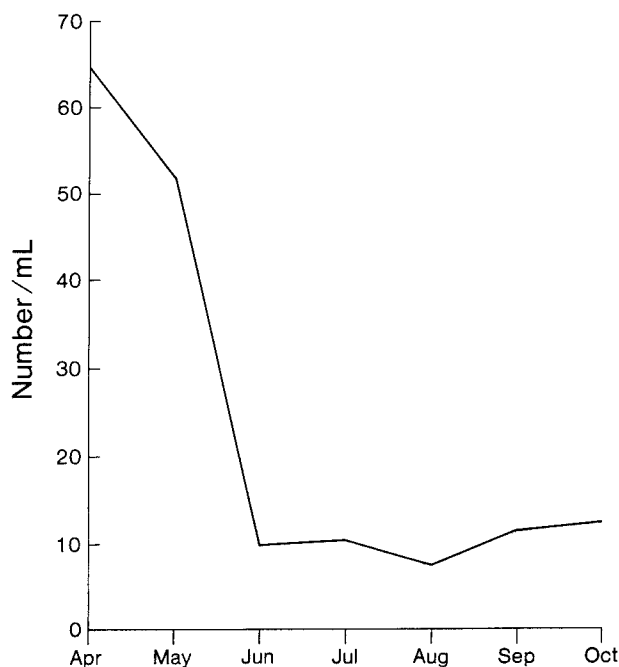


Fig. 10. Monthly mean phytoplankton counts (April-October), Lake Sharpe, 1970-75.

spring in 1966-69, but only about one-sixth those in spring in 1970-75. The reduced summer densities during the later period were probably due to increased discharge rates ( $r = -0.39$ ;  $P < 0.05$ ). *Asterionella* dominated the phytoplankton in April, May, and October in most years. The June-September phytoplankton community was usually dominated by *Synedra* or *Fragilaria* during 1970-71; blooms of *Gloeocystis*, *Oocystis*, *Cyclotella*, and *Melosira* were evident in some years.

The mean standing crop of phytoplankton was consistently highest at stations 1 and 2, decreased sharply upstream at stations 3 and 4, and continued near this low level at stations farther upstream (Fig. 11). Densities at stations 1 and 2 averaged about 10 times those at stations 3-7. The diatom *Asterionella* numerically dominated the phytoplankton at stations 1 and 2; *Synedra*, *Fragilaria*, *Melosira*, *Cyclotella*, and *Ankistrodesmus* were also common. *Rhodomonas* and *Cryptomonas* were also present in high numbers at these stations during 1966-69. *Synedra*, *Asterionella*, *Diatoma*, *Gyrosigma*, *Fragilaria*, and *Navicula* dominated at different times at stations 3-5; *Cryptomonas* and *Rhodomonas* were also

important during 1966-69. Green algae, principally *Ankistrodesmus*, *Scenedesmus*, *Actinastrium*, and *Oocystis* were also common at these three stations. *Asterionella*, *Fragilaria*, and *Navicula* were the three most common genera at stations 6 and 7, followed by *Cyclotella*, *Diatoma*, *Tabelaria*, and *Oscillatoria*.

The increase in the mean phytoplankton standing crop in Lake Sharpe during 1970-75 may have been due to nutrient additions to the water mass as it moved through the reservoir. Martin et al. (1980) concluded that phytoplankton production in the lower four Missouri River reservoirs was limited by available phosphorus. They showed that the phytoplankton standing crop and gross primary production during 1971-72 averaged higher in Lake Sharpe than in Lake Oahe, but lower than in downstream Lake Francis Case and Lewis and Clark Lake. Mean particulate phosphorus concentrations showed the same trend. The most likely sources of increased phosphorus in Lake Sharpe during 1970-75 were sewage lagoon discharges at Pierre, Fort Pierre, and Lower Brule and runoff from farmland adjacent to the reservoir, where irrigation and row-crop farming were increasing. Two other possible sources of nutrients were the overwintering cattle in feedlots located

in several draws bordering the reservoir and Canada geese (*Branta canadensis*) in the area just downstream from station 3. Numbers of geese using the area during the period from September to March each year quadrupled over the 10-year period 1966-75, and nearly tripled between 1970 and 1975 (South Dakota Department of Game, Fish and Parks, unpublished data). Estimated peak numbers exceeded 20,500 in 1974.

Other factors also seemed to influence phytoplankton standing crop in Lake Sharpe. The relations between phytoplankton densities and five environmental variables during 1970-75 were examined individually with correlation analyses, as shown in the following summary.

Variable	<i>r</i>	<i>P</i>
Conductivity ( $\mu\text{mho/cm}$ ) at 1 m	0.25	<0.01
Discharge ( $\text{m}^3/\text{s}$ ) from Big Bend powerhouse	-0.12	<0.05
Transmissivity (%) at 1 m	0.13	<0.05
Turbidity (JTU) at 1 m	-0.11	>0.05
Water temperature ( $^{\circ}\text{C}$ ) at 1 m	0.16	<0.01

Both positive and negative relations were indicated, but all of the coefficients were low and suggest the probable interaction between the phytoplankton and a number of factors not analyzed. The great variability of phytoplankton densities also probably contributed to the low correlation coefficients; however, multivariate analysis indicated that 52% of the variation in densities was associated with three variables: conductivity, water discharge from Big Bend Dam, and water temperature. Berner (1951) and Damann (1951) believed that phytoplankton populations in the Missouri River were largely limited by high turbidity and high current velocity; Neel et al. (1963) also concluded that turbidity was an important factor, but judged that current velocity was less limiting in the reservoirs. Benson and Cowell (1968) hypothesized that turbidity was the major factor limiting phytoplankton abundance in the Missouri River system, and Hudson and Cowell (1967) showed an inverse (but nonsignificant) correlation between net phytoplankton abundance and turbidity in Lewis and Clark Lake. Although I was unable to demonstrate cause and effect relations from the data available, I concluded that discharge rate at Big Bend Dam probably was the principal factor governing the interaction of

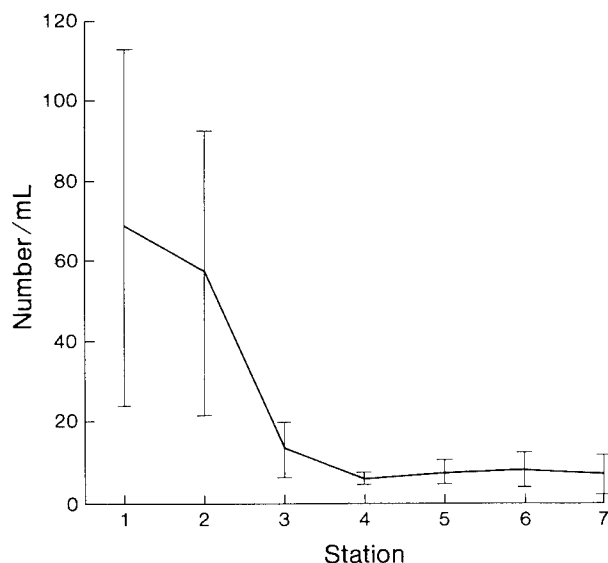


Fig. 11. Mean phytoplankton counts at each sampling station, Lake Sharpe, 1970-75. Vertical lines show limits of the 0.95 fiducial interval for the means. See Fig. 1 for location of stations.

environmental variables and the phytoplankton populations in Lake Sharpe.

### Zooplankton

The crustacean zooplankton community consisted of 29 species (Table 8). The more commonly recurring organisms were three species of cyclopoid copepods, *Cyclops bicuspidatus thomasi*, *C. vernalis*, and *Mesocyclops edax*; two species of calanoid copepods, *Diaptomus forbesi* and *D. sicilis*;

Table 8. Species of crustacean zooplankton identified in tow-net samples, Lake Sharpe, 1966-75.

#### Copepoda

##### Cyclopoida

*Cyclops bicuspidatus thomasi*  
*C. varicans rubellus*  
*C. vernalis*  
*Eucyclops agilis*  
*Mesocyclops edax*  
*Tropocyclops prasinus*

##### Calanoida

*Diaptomus ashlandi*  
*D. clavipes*  
*D. forbesi*  
*D. sicilis*  
*D. siciloides*

#### Cladocera

*Acantholeberis curvirostris*  
*Alona rectangularis*  
*Alonella* sp.  
*Bosmina longirostris*  
*Camptocerus rectirostris*  
*Ceriodaphnia pulchella*  
*Chydorus sphaericus*  
*Daphnia galeata mendotae*  
*D. pulex*  
*D. retrocurva*  
*D. schödleri*  
*Diaphanosoma brachyurum*  
*Kurzia laticornis*  
*Leptodora kindtii*  
*Leydigia quadrangularis*  
*Macrothrix laticornis*  
*Moina affinis*  
*Pleuroxus denticulatus*

and four species of cladocerans, *Daphnia retrocurva*, *D. schödleri*, *Diaphanosoma brachyurum*, and *Leptodora kindtii*. Although there were annual variations in the total number of species, no significant trend over time was discernible.

Copepods accounted for about 80% of the total zooplankton density (no./L) during 1966-75. Calanoid copepods made up 41% of the total, cyclopoid copepods about 38%, and cladocerans the rest. Most of the samples were dominated by three genera, *Daphnia*, *Cyclops*, and *Diaptomus*. Cyclopoid copepods were more abundant than calanoid copepods at stations 1 and 2, but beginning at station 3 their proportions were reversed. Cladocerans accounted for about 25% of the total at station 1; their contributions decreased at stations 2 and 3, but then increased slightly upstream, while those of copepods decreased (Fig. 12).

There were changes in the composition of the crustacean zooplankton during 1966-75. The importance of cyclopoid copepods decreased, whereas that of calanoid copepods and cladocerans increased (Fig. 13). Correlation analysis indicated that cyclopoid numbers were inversely related to the mean discharge rate at Big Bend Dam during summer ( $r = -0.40$ ;  $P < 0.01$ ). Although calanoid copepods displaced cyclopoid copepods as the dominant group at every station, the shift in composition was sharpest near midreservoir. At sta-

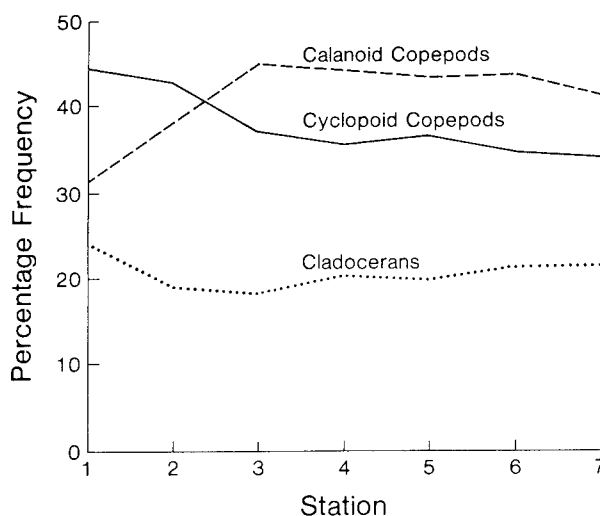


Fig. 12. Mean percentage contributions by the three major groups of crustacean zooplankton at each sampling station, Lake Sharpe, 1966-75. See Fig. 1 for location of stations.

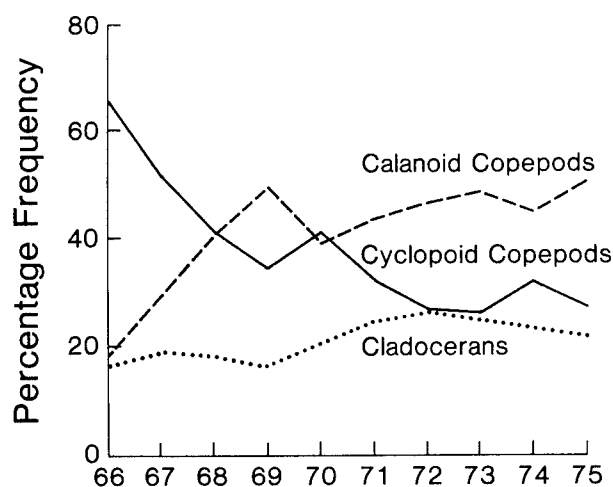


Fig. 13. Seasonal (April-October) mean percentage contributions by the three major groups of crustacean zooplankton, Lake Sharpe, 1966-75.

tion 3, for example, the cyclopoid group accounted for nearly 75% of the zooplankton in 1966; after 1968, however, cyclopoids contributed only 23 to 34%, whereas calanoids made up 46 to 57%. Contributions by cladocerans also rose slightly during 1966-75. Overall, calanoid copepods became the most important component of the crustacean zooplankton after 1970.

The species composition of the Lake Sharpe crustacean zooplankton was similar to that reported in upstream Lake Oahe by June (1974) and Selgeby (1974). The numerically dominant

species in Lake Sharpe were also reported to be abundant in downstream Lake Francis Case and Lewis and Clark Lake (Tash et al. 1966; Cowell 1967, 1970; Selgeby 1968; Martin and Novotny 1977). The similarity in the composition of the zooplankton communities in these four reservoirs suggests that the rapid water exchange served to transport a more or less common community through this portion of the Missouri River impoundment system.

The shift from cyclopoid to calanoid dominance in the zooplankton community of Lake Sharpe during 1966-75 may have been associated with a general decline in reservoir productivity that usually occurs within a few years after impoundment (Neel 1968), and several investigators have noted that calanoid copepods tend to be more successful than cyclopoid copepods or cladocerans in oligotrophic waters (Patalas 1972, 1975; Patalas and Salki 1973; Andersson et al. 1975; McNaught 1975). However, I believe that the decrease in cyclopoid copepods was largely due to increased summer discharges beginning in 1969. This conclusion is based on the inverse relation that was shown between cyclopoid numbers and summer discharge rates at Big Bend Dam.

The mean total standing crop of zooplankton during the open-water period fluctuated during 1966-75 (Table 9), but showed no significant trend with time. Average density for the 10-year period was 18 organisms per liter. A general increase through 1969 was overshadowed by higher levels

Table 9. Seasonal (April-October) mean numbers and ash-free dry weights of zooplankton and mean ash-free dry weight of individual organisms in tow-net samples, Lake Sharpe, 1966-75.

Year	No. per liter		Weight <sup>a</sup> (mg/m <sup>3</sup> )		Mean weight per organism (mg)
	Mean	Range	Mean	Range	
1966	14.9	4.1-64.2	41.4	8.2-113.2	2.8
1967	16.6	1.2-82.5	53.5	10.0-226.1	3.2
1968	20.7	4.2-68.2	68.3	18.4-189.1	3.3
1969	20.8	2.2-114.0	—	—	—
1970	13.1	2.5-67.4	26.9	26.9-91.7	2.1
1971	20.5	2.0-85.7	53.2	10.2-139.4	2.6
1972	26.9	3.6-101.5	69.6	12.3-201.8	2.6
1973	24.6	1.6-139.1	84.6	4.0-519.7	3.1
1974	14.0	2.5-54.3	59.3	8.9-230.6	4.2
1975	12.3	2.1-52.9	50.1	6.3-144.1	3.5

<sup>a</sup>Ash-free dry weights were not determined for samples collected in 1969 nor for most of those collected in 1970.

of abundance during 1972-73. Abundance decreased noticeably thereafter; density in 1975 was about half that in 1972 and 1973, and was the lowest recorded during the 10-year period.

The mean ash-free dry weights of zooplankton showed nearly the same relative annual variations shown by the counts, except that the peak for the weights was in 1973 rather than in 1972 (Table 9). A probable explanation for this discrepancy lies in the unusually heavy bloom of *Asterionella* that occurred in May 1973. This phytoplankton was retained by our nets and therefore included in the ash-free dry weights. The mean weights per organism also varied during 1966-75, but no significant trend over time was indicated.

Zooplankton densities were generally highest in June and lowest in April (Fig. 14). The cladocerans—chiefly *Daphnia*—peaked in May, and cyclopoid and calanoid copepods in June. Calanoid copepods usually dominated the zooplankton through July, but cyclopoid copepods slightly exceeded the calanoids later in the season in most years.

The seasonal pattern of zooplankton abundance in Lake Sharpe lagged the seasonal phytoplankton cycle. The seasonal cycle among the major zooplankton components was similar to that reported in upstream Lake Oahe (June 1974) and

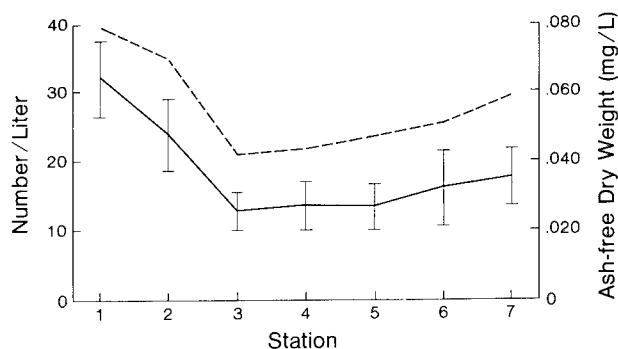


Fig. 15. Mean counts (solid line) and ash-free dry weights (broken line) of net zooplankton, by station, Lake Sharpe, 1966-75. Vertical limits of the 0.95 fiducial interval for the means. See Fig. 1 for location of stations.

in downstream Lewis and Clark Lake (Tash et al. 1966; Novotny and Martin 1980). The June peaks in Lake Francis Case and Lewis and Clark Lake, however, were attributable to cyclopoid copepods—principally *Cyclops* (Benson and Cowell 1968; Cowell 1970)—whereas those in Lake Sharpe were attributable to calanoid copepods (chiefly *Diaptomus*). Benson and Cowell (1968) showed the seasonal peak for *Daphnia* to be in June, whereas in Lake Sharpe it was in May.

There were notable differences in the mean standing crop of zooplankton in different localities of the reservoir (Fig. 15). Densities were usually highest at station 1, sometimes at station 2, and occasionally (April and October) at station 7. Mean densities were at least twice as high at station 1 as at stations 3-7 and were usually lowest at stations 3-5. Densities were most variable at station 1, followed by stations 6 and 2.

The variable spatial pattern of zooplankton abundance seemed to be most closely related to water temperature and turbidity. Multiple regression analysis indicated that 36% of the variation in numbers of organisms was associated with these two variables. A highly significant positive relation was also indicated between zooplankton numbers and transmissivity at 1 m ( $r = 0.29$ ;  $P < 0.01$ ), thus further supporting the general conclusion that zooplankton abundance in Lake Sharpe was generally lower and less variable in the more turbid waters at stations 3-5 and significantly higher in the clearer waters at stations 1 and 2 and 6 and 7.

The mean standing crop of zooplankton in Lake Sharpe was generally lower than standing crops

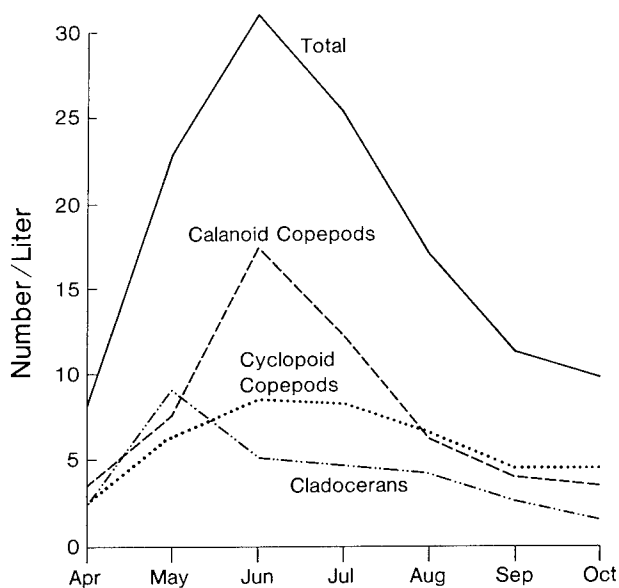


Fig. 14. Estimated monthly mean density of zooplankton (April-October), based on sample counts, Lake Sharpe, 1966-75.

reported in upstream Lake Oahe, but higher than those in downstream Lake Francis Case and Lewis and Clark Lake. During the 5-year period 1966–70, the seasonal mean density (no./L) of zooplankton in Lake Oahe ranged from 25 to 39 and averaged 32 (June 1974), whereas that in Lake Sharpe ranged from 13 to 21 and averaged 17. The mean density in the outflow from Lake Francis Case in 1966–72 ranged from 6 to 20 and averaged 13 (Martin and Novotny 1977); and the density in the outflow from Lewis and Clark Lake in 1964–73 ranged from 4 to 19 and averaged 10 (Novotny and Martin 1980). The cause of the apparent progressive decrease in standing crops of zooplankton in a downstream direction is not clear, but may be associated with turbidity. However, Novotny and Martin (1980) suggested that zooplankton abundance in Lake Sharpe, Lake Francis Case, and Lewis and Clark Lake was related to nutrient releases from Lake Oahe.

### Benthos

During the special study of the benthos in 1967–68, chironomid larvae were numerically dominant throughout the sampling period (Table 10). Chironomids accounted for more than 90% of the total number of organisms collected and for 88 to 96% each month. Oligochaetes ranked second in importance, followed by Ephemeroptera nymphs (*Hexagenia* and *Caenis*) and *Chaoborus*. The benthos also included larval ceratopogonids (*Culicoides*) and Trichoptera (*Oecetis*), and a few organisms of other taxa.

Table 10. Mean density (no./m<sup>2</sup>) of benthic organisms, by major groups, Lake Sharpe, 1967–68.

Taxon	Mean no.	Percent of total
Chironomidae	963	90.8
Oligochaeta	36	3.4
Ephemeroptera	12	1.1
<i>Chaoborus</i>	12	1.1
Ceratopogonidae	10	0.9
Nematoda	8	0.8
Trichoptera	2	0.2
Other <sup>a</sup>	17	1.6

<sup>a</sup>Includes Nematoda, Mollusca, Arachnida, Amphipoda, Hemiptera, Hirudinea, Odonata, and miscellaneous Diptera.

The total mean density of benthic organisms was estimated to be 1,060/m<sup>2</sup>. The mean wet weight of a random subsample of 100 organisms taken from each of the first 1,000 samples was 0.06 g. Extrapolation yielded an estimated benthic standing crop of 1.15 g/m<sup>2</sup>. This estimate is well below any of the regional averages for standing crops given by Hayes (1957), and lower than any of the standing crop estimates listed by Moyle (1961).

The abundance of benthic organisms was rather uniform throughout the reservoir, except at station 6 (Table 11). Exclusive of embayments and backwaters, abundance was highest at station 5. Chironomid larvae were least abundant at station 6, and their mean numbers generally decreased downstream from station 5. Abundance of oligochaetes was greatest in Hipple Lake and the two lower reservoir stations (1 and 2). Ephemeropteran nymphs (chiefly *Hexagenia*) were most abundant at station 3; this group was poorly represented in the upper reservoir (except in Hipple Lake). *Chaoborus* was abundant in Hipple Lake, but scarce elsewhere. Ceratopogonid larvae were also abundant in Hipple Lake, but scarce at both the upper and lower main reservoir stations. Nematodes were most common at the upper reservoir station (7) and poorly represented at stations 1–5 and Hipple Lake.

Water depth appeared to be one of the most important factors governing the benthos distribution in Lake Sharpe (Table 12). Densities, for example, were inversely related to depth ( $r = -0.21$ ;  $P < 0.01$ ). Abundance was most variable in the littoral and least variable in the sublittoral.

The mean numbers of benthic organisms differed with the various substrates (Table 13). Average numbers were highest in shale along the east shore at station 7, and lowest in sand in the vicinity of stations 6 and 7.

Total benthos abundance peaked in late winter and was lowest in summer (Fig. 16). Summer minima were similar in 1967 and 1968. The winter peak was largely attributable to increased abundance of chironomids; the abundance of oligochaetes also increased during February–April. Seasonal changes in the Lake Sharpe benthos were similar to those outlined by Welch (1952) for a second-order (dimictic) lake.

Benthos in Lake Sharpe, like that in downstream Lake Francis Case, was dominated by

Table 11. Mean density (no./m<sup>2</sup>) of benthic organisms, by major groups, stations, and localities, Lake Sharpe, 1967-68.

Taxon	Station transect or locality							Hipple Lake
	1	2	3	4	5	6	7	
Chironomidae	968	876	1,129	1,059	1,487	410	1,060	933
Oligochaeta	44	46	4	26	31	29	36	88
Ephemeroptera	34	2	39	15	20	1	<1	13
<i>Chaoborus</i>	0	<1	1	1	42	2	<1	183
Ceratopogonidae	2	1	12	4	64	6	2	66
Nematoda	1	1	<1	4	2	7	23	<1
Trichoptera	2	<1	1	5	1	1	2	1
Other <sup>a</sup>	14	15	13	15	10	12	27	11
Total	1,065	942	1,199	1,129	1,657	468	1,151	1,295

<sup>a</sup>See footnote, Table 10, for list.Table 12. Mean density of benthic organisms (no./m<sup>2</sup>), by major group and depth, Lake Sharpe, 1967-68.

Taxon	Littoral				Sublittoral			Profundal		
	1	1	2	3	4	5-7	8-10	11-14	15-19	20
Chironomidae	798	1,319	1,364	1,225	100	94	645	855	536	402
Oligochaeta	111	96	94	81	57	47	32	57	108	142
Ephemeroptera	92	49	130	159	62	125	40	23	51	19
<i>Chaoborus</i>	38	26	89	323	221	53	19	19	19	—
Ceratopogonidae	113	168	53	45	43	38	30	23	21	—
Nematoda	21	36	104	55	62	47	19	38	23	19
Trichoptera	51	19	40	47	42	34	25	—	19	19
Other <sup>a</sup>	49	49	60	47	47	42	26	19	36	57
Total	1,273	1,762	1,934	1,982	634	480	836	1,034	813	658

<sup>a</sup>See footnote, Table 10, for list.Table 13. Mean density (no./m<sup>2</sup>) of benthic organisms in different bottom types, Lake Sharpe, 1967-68.

Bottom type	No. of samples	Mean no. of organisms
Shale rocks	33	1,722
Mud and sand	133	1,277
Mud	958	1,087
Bank gravel	59	944
Sand	85	126

chironomid larvae. Cowell and Hudson (1968) found that, numerically, chironomids accounted for 93% of the bottom fauna in Lake Francis Case and oligochaetes for 6%; *Hexagenia*, Ceratopogonidae, and *Chaoborus* were also present. In contrast, Jones and Selgeby (1974) reported the benthos of upstream Lake Oahe to be dominated by oligochaetes (61%), followed by chironomids (37%); Ephemeroptera, Trichoptera, and Ceratopogonidae were also present.

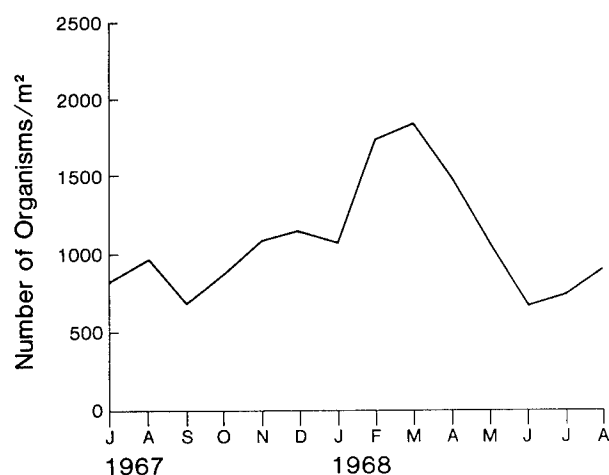


Fig. 16. Estimated monthly mean density of benthic organisms, Lake Sharpe, 1967-68.

Domination of the benthos by chironomids seems typical in new reservoirs (Ioffe 1961). Excepting station 6, abundance was rather uniform throughout the length of Lake Sharpe, although there was a tendency for it to average slightly higher in midreservoir than in the lower or upper portions. Although abundance was inversely related to depth and turbidity, differences in species composition within major taxa probably accounted for some of the observed variation. The general features of the benthos distribution in Lake Sharpe have been shown for Lake Oahe (Jones and Selgeby 1974) and other localities (Ökland 1964; Thut 1969). However, it is likely that the composition and abundance of the benthos in Lake Sharpe underwent later changes, inasmuch as the survey described here was conducted in 1967-68, soon after the reservoir filled.

## Conclusion

The significant events in the water regimes of Lake Sharpe were (1) filling (1963-65) and attainment of full operational status in 1966, (2) increased summer discharge rates beginning in 1969, and (3) increased peaking operations beginning in 1973. The rapid exchange of the water mass became the most notable feature of Lake Sharpe. The variability in timing and rate of exchange governed

environmental conditions and the biological community within the reservoir. Because of increasing demand for hydroelectric power, it appears that the rapid water-exchange regimen will continue. Increased peaking operations and accompanying changes in the discharge pattern and rates can be expected, with concomitant impacts on the biological community.

## Acknowledgments

I thank the many staff members of the North Central Reservoir Investigations who participated in the monthly limnology cruises on Lake Sharpe during the 10-year study—especially L. G. Beckman, who participated in all of the cruises; G. K. O'Bryan, R. G. Rada, and others who assisted in processing the plankton samples; and J. H. Grover, who collected and processed the benthos samples.

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# Zooplankton Biomass Exchange in Lake Sharpe, South Dakota, 1974-1975

by

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## Abstract

The relation between zooplankton density and biomass in the water released and the rate of water release from Lakes Oahe and Sharpe through Oahe and Big Bend dams was investigated during 1974-75. The relation of zooplankton density in water to the water release rate was inverse at Oahe Dam, but direct at Big Bend Dam. Differences in the depth and manner of water intake, water-level regimen, thermal structure of the water masses of Lakes Oahe and Sharpe, and zooplankton behavior most likely accounted for these differences in relations. More zooplankton (in both numbers and biomass) was lost from Lake Sharpe through Big Bend Dam than was gained from Lake Oahe through Oahe Dam. Fish eggs and larvae—mostly freshwater drum (*Aplodinotus grunniens*)—captured in the forebay of Big Bend Dam almost certainly passed the dam. No eggs or larvae were caught in collections made from water released at Oahe Dam.

Lake Sharpe (South Dakota) functions as a mainstream power generation reservoir and also reregulates the discharge from upstream Lake Oahe. The annual mean water retention time in the reservoir ranged from 27 to 46 days in 1966-75, and monthly means from 13 to 87 days (determinations based on records furnished by the U.S. Army Corps of Engineers, Omaha District). Further, particularly in 1973-75, the water releases from Lake Sharpe through Big Bend Dam were routinely made on a peaking regimen. (Peaking here refers to the highly variable water release rate associated with fluctuating electric power demands during a 24-h period.) Water release rates from Lake Sharpe sometimes shifted from nil to nearly 2,900 m<sup>3</sup>/s within a few minutes.

Questions about the effects of such rapid and variable discharges on the fish stocks of the reser-

voir led to the initiation of a study in 1974 of the effects of peaking of reservoir discharge on fish movement in the tailwaters, on fish and zooplankton distribution in the intake areas, on the abundance and mortality of larval and juvenile fish and zooplankton that passed through the powerhouses, and on general water currents and associated ecological conditions.

We describe the relation observed between the density of zooplankton in the discharge and the rate of water discharge at Oahe and Big Bend dams, and estimate the gain and loss of zooplankton and ichthyoplankton from Lake Sharpe.

The zooplankton discharged into and out of Lake Sharpe was examined by sampling in the Oahe Dam tailwater and in the forebay and tailwater of Big Bend Dam (Fig. 1) at weekly intervals from May to October 1974 and from June to October 1975. Lakes Oahe and Sharpe and Oahe and Big Bend dams were described by June (1974, 1987).

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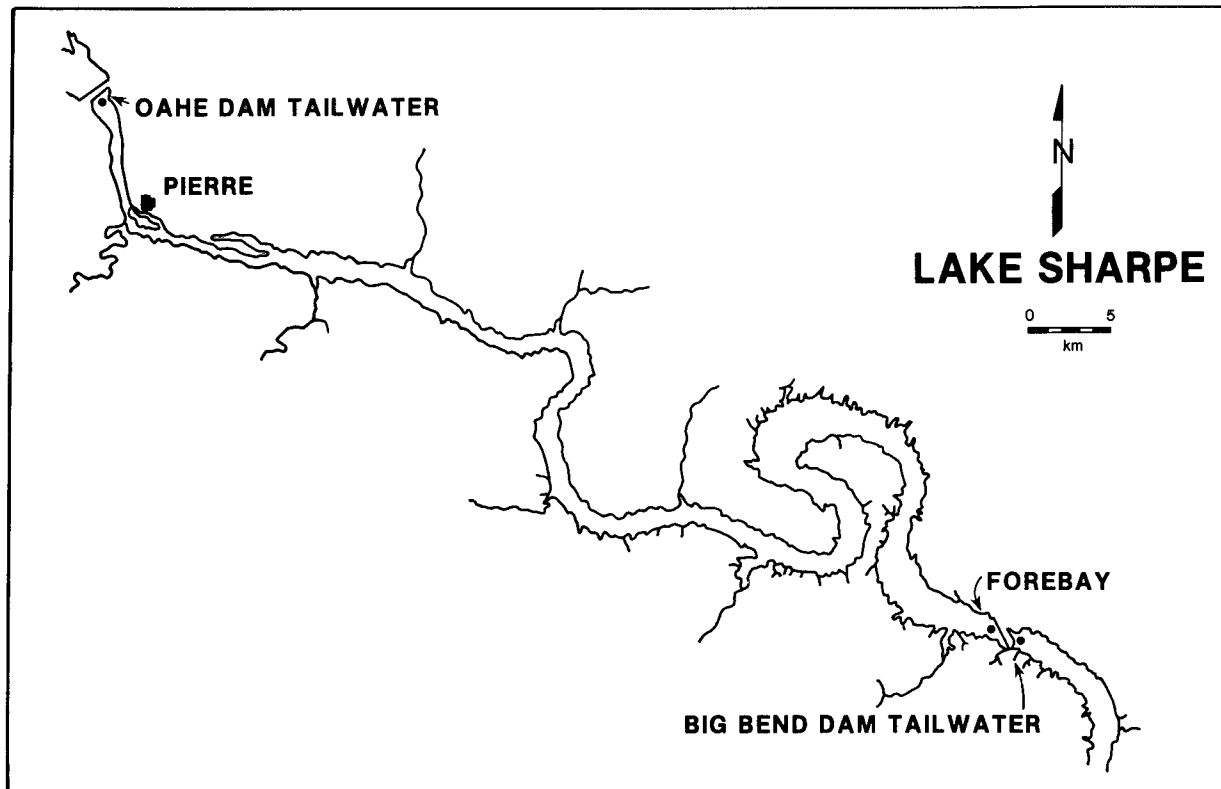


Fig. 1. Lake Sharpe, showing locations of sampling stations (solid circles) in Oahe Dam tailwater and in the forebay and tailwater of Big Bend Dam.

## Methods

Zooplankton was collected in the Oahe Dam tailwater with four Miller samplers (Miller 1961), each equipped with a flowmeter and a No. 10 nylon net (0.153-mm mesh), suspended from a cableway that spanned the tailrace. The samplers were attached with interconnected individual cables at 40-m intervals along the cableway (beginning 10 m from either shore) and were operated about 1 m beneath the surface. A boat was used to attach or remove the samplers. A davit and winch on shore were used to raise or lower the gear. This arrangement enabled simultaneous sampling at four fixed locations in the tailrace during different combinations of water release from seven draft tubes. Inasmuch as the intake structure at Oahe Dam removed water from the metalimnion, we believed that the discharge of plankton into Lake Sharpe would be estimated more accurately from collections in the tailrace than in the forebay.

Because there was no cableway over the tailrace of Lake Sharpe, we collected zooplankton in the forebay of Big Bend Dam. A Miller sampler was operated at depths of 1, 11, and about 22 m, suspended from a boat that was moored to a buoy when water was being discharged, or towed when there was no discharge. We believe that the samples collected were comparable with those collected in the Lake Oahe tailrace because the water intake structure at Big Bend Dam extends the full depth of the forebay (ca. 24 m), and it is improbable that zooplankton could swim away from the intake area (forebay), given the volume of water moving through it under discharge conditions. The proportions in the mixture of water discharged that was contributed by the three layers sampled are unknown and probably varied with the rate of discharge. However, for the present work we accepted the mean of the zooplankton densities measured at the three depths as a reasonable estimate of the density in the water discharged.

The plankton from each sampler was washed into a serially numbered jar, preserved with 5% formalin mixed with phloxine B dye, and returned to the laboratory for identification, enumeration, and determination of ash-free dry weights (AFDW) by methods described by the American Public Health Association et al. (1971).

Sampling at both sites was done over a 4- to 5-h period on each date. Samplers were fished for 5 min at the beginning of each hour to correspond with the Corps of Engineers record of water releases from the powerhouses. At Big Bend Dam, the three tows were taken sequentially from top to bottom as rapidly as possible.

Ancillary samples to determine losses of rotifers, nauplii, and phytoplankton were taken in both Oahe and Big Bend tailwaters in 1975. Two 5-min tows with a pair of closely yoked Miller samplers—one equipped with a No. 10 nylon net and the other with a No. 20 nylon net (0.80-mm mesh)—were made in mid-channel at a depth of 1 m.

The zooplankton samples were enumerated according to the method described by June (1974), except that phytoplankton and rotifers in the No. 20 net samples were identified to genus. The reported zooplankton densities (expressed as no./m<sup>3</sup>) represent the mean of sets of samples taken on the hour on each date—four simultaneous horizontal samples in the Oahe Dam tailwater and three vertically stratified samples at Big Bend Dam.

Although the samples described were all routinely examined for fish eggs and larvae, additional 30-min tows were made to sample them in the forebay of Big Bend Dam with a 0.5-m net of No. 00 nylon (0.75-mm mesh) during the sampling seasons in 1974 and 1975 and in Oahe Dam and Big Bend Dam tailwaters during 1974. The 0.5-m net samples were preserved with 5% buffered formalin; the fish eggs and larvae were enumerated, and the larvae identified to the lowest possible taxon.

Water release data were provided by the U.S. Army Corps of Engineers, Omaha District.

## Results and Discussion

### *Release Rate and Zooplankton Densities*

Zooplankton density in the Oahe Dam tailwater tended to decrease as hourly water release rates

Table 1. *Water discharge and density of zooplankton in the tailwater of Oahe Dam, 30 July 1974.*

Time	Discharge (m <sup>3</sup> /s)	Zooplankton (no./m <sup>3</sup> )
0800	156	50,415
0900	333	47,433
1000	793	25,189
1100	1,179	38,370
1200	1,288	30,971

increased; a typical example of changes in density is given in Table 1. A similar functional relation existed between water release rates and density of zooplankters in the water released during the sampling seasons in 1974 and 1975. A plot of the data (Fig. 2) showed a wide scattering of points, with a cluster of unusually high values for 1975. We believe that the outliers above about 50,000 organisms/m<sup>3</sup> resulted from faulty flowmeter readings (meter malfunction, blockage by debris during sampling, or misreading of the dials), because each of the deviant mean values was due to a single low meter reading among the four net samples taken on a given date (deviant readings fell between 1,000 and 2,000 revolutions below the

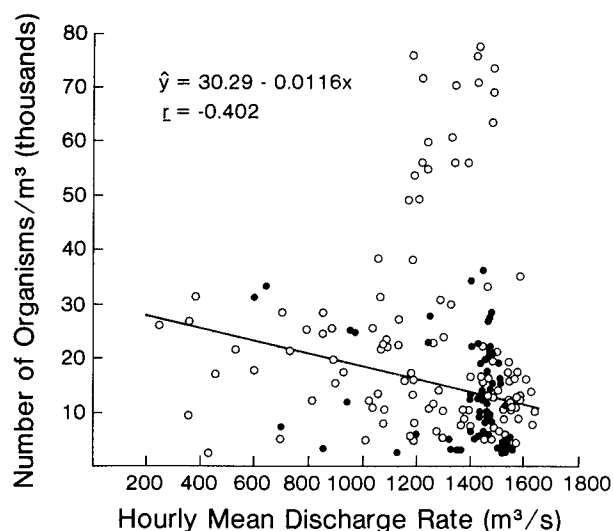


Fig. 2. Relation between mean numbers of zooplankters discharged and mean hourly discharge rate at Oahe Dam, Lake Sharpe, in 1974 (dots) and 1975 (open circles).

range of the other readings), and actual counts of organisms in the individual samples showed no corresponding discrepancies. Finally, all but four of the deviant readings were attributable to the same flowmeter. If the deviant readings are deleted, an analysis of covariance of the remaining data indicated no significant differences between the linear regression coefficients or the adjusted means between years ( $P > 0.05$ ). A common regression line fitted to the data for the 2 years combined indicated a significant inverse relation ( $t = 5.95$ ;  $P < 0.01$ ) between release rate and zooplankton density in Oahe Dam tailwaters. Thus the total biomass of zooplankton lost to Lake Sharpe was a function of total discharge and not of discharge rate.

Although we did not set out to investigate the specific cause of the relation observed, we believe that the dilution of zooplankton with increased discharge was associated with the design of the intake structures, which permitted disproportionate withdrawal of hypolimnetic water at increased release rates. June (1974), for example, showed that the lower limit of thermal stratification of lower Lake Oahe coincided with the lower level of the intake structures (22.5 m above the base of Oahe Dam and 33.2 m above the original river bed), and suggested that variations in the metalimnion during the summer were governed by the water discharge regimen of Oahe Dam. Assuming that zooplankters were largely confined above the hypolimnion, any increased intake of denser, more viscous hypolimnetic water at higher release rates would result in a corresponding reduction in zooplankton in the outflow.

In contrast to the findings at Oahe Dam, high densities of zooplankton in the outflow at Big Bend Dam were associated with high release rates. Covariance analysis of the data plotted for 1974 and 1975 (Fig. 3) indicated no significant differences ( $P > 0.05$ ) between the slopes or the adjusted means between years. A common linear regression line was fitted to the data ( $t = 2.86$ ;  $P < 0.01$ ), although the relationship may be nonlinear. Nevertheless, the amount of zooplankton lost in the outflow from Lake Sharpe was directly related to discharge rate, the greatest losses being associated with the highest discharges.

Differences in the manner of water intake (surface to bottom at Big Bend Dam), water-level regimen, and seasonal thermal structure of the water

masses of Lakes Oahe and Sharpe—coupled with zooplankton behavior—probably accounted for the observed difference in the relation between water release rates and zooplankton densities in the water released at Oahe and Big Bend dams. The low observed  $r$  values may have reflected seasonal variability in zooplankton standing crops in the two reservoirs; sounder  $r$  values might have resulted from more intense sampling.

### Water Releases and Zooplankton Exchanges

The estimated densities of zooplankton in water released into and from Lake Sharpe (Table 2), which were based on the assumption that the samples taken during a week were representative of the density of zooplankton in the discharges for that week, indicated a substantial exchange of biomass. For the week of 7 July 1974, for example, the estimated mean daily import was 10,825 organisms (37 mg AFDW)/m<sup>3</sup>, and the daily export was 16,360 organisms (56 mg AFDW)/m<sup>3</sup>. The total estimated import for that week was  $1.319 \times 10^{15}$  organisms or 4,521 metric tons AFDW, and the estimated export was  $1.833 \times 10^{15}$  organisms or 5,781 metric tons AFDW. Although the estimates are crude, the biomass exported from Lake Sharpe during this study clearly exceeded that imported from Lake Oahe.

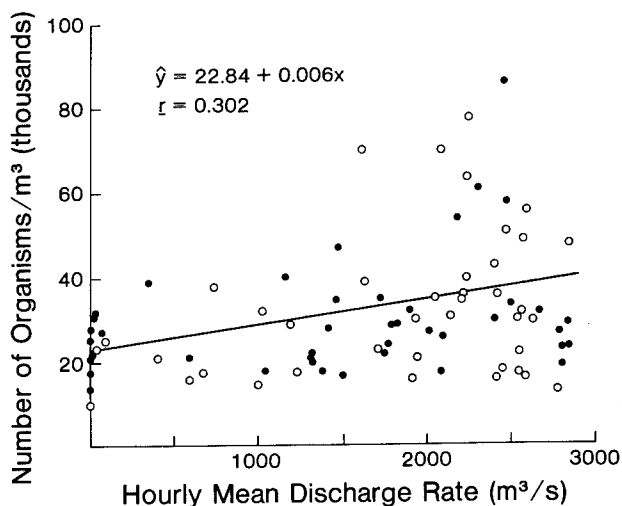


Fig. 3. Relation between mean numbers of zooplankters discharged and mean hourly water discharge rate at Big Bend Dam, Lake Sharpe, 1974 (dots) and 1975 (open circles).

Table 2. *Estimated mean density and ash-free dry weights of zooplankton in water discharged from Lake Oahe into Lake Sharpe and in water discharged from Lake Sharpe on different dates (24-h periods), May–October 1974–75 (NS = no sample).*

Year, month, and day	Lake Oahe discharge		Lake Sharpe discharge <sup>a</sup>	
	Density (no./m <sup>3</sup> )	Weight per day (mg/m <sup>3</sup> )	Density (no./m <sup>3</sup> )	Weight per day (mg/m <sup>3</sup> )
1974				
May				
26	23,269	92.5	NS	NS
June				
2	35,565	158.7	53,659	150.1
9	30,075	84.3	47,487	51.6
16	14,174	35.1	NS	NS
23	NS	NS	23,175	48.3
30	NS	NS	42,011	91.7
July				
7	10,825	37.1	16,360	56.2
14	12,045	41.2	22,457	51.6
21	19,577	65.0	32,191	77.3
28	31,585	78.3	31,222	96.3
August				
4	9,913	28.6	26,521	64.1
11	11,711	41.6	30,120	67.7
18	21,246	73.6	35,140	71.0
25	33,078	86.3	45,720	124.9
September				
1	18,734	60.5	25,932	44.0
8	10,853	40.8	29,252	48.1
15	6,074	22.7	40,555	45.3
22	12,085	47.3	23,102	38.1
29	7,076	19.4	23,061	34.8
October				
6	20,422	86.8	23,090	34.5
Mean	16,068	51.8	28,890	61.2
1975				
June				
1	69,402	184.3	96,195	227.6
8	52,025	125.0	39,817	89.8
15	73,563	130.0	32,499	111.5
22	4,841	9.5	55,177	185.8
29	9,363	32.0	24,049	57.4
July				
6	47,031	91.3	50,647	180.9
13	16,506	31.6	36,941	147.3
20	19,876	49.1	55,077	199.1
27	12,648	29.1	38,504	151.3
August				
3	10,043	33.2	23,618	92.8
10	24,570	93.5	33,717	102.0
17	9,538	30.8	30,265	91.8
24	4,696	19.1	19,189	82.6
31	8,765	34.9	28,419	73.3

Table 2. *Continued.*

Year, month, and day	Lake Oahe discharge		Lake Sharpe discharge <sup>a</sup>	
	Density (no./m <sup>3</sup> )	Weight per day (mg/m <sup>3</sup> )	Density (no./m <sup>3</sup> )	Weight per day (mg/m <sup>3</sup> )
September				
7	6,486	25.4	18,509	41.5
21	4,173	14.7	15,841	43.1
28	3,197	12.9	NS	NS
October				
5,12 <sup>b</sup>	5,365	28.1	5,444	16.7
Mean	22,909	57.5	35,678	112.1

<sup>a</sup>Lake Sharpe discharge estimated on basis of collections made from the intake water at Big Bend Dam.

<sup>b</sup>Discharge sampled at Lake Oahe on 5 October and at Lake Sharpe on 12 October.

Net total biomass losses from Lake Sharpe during the seasonal sampling periods were estimated to be 11,565 and 105,291 metric tons AFDW in 1974 and 1975, respectively; thus, roughly 1.7 times more biomass was lost in the water released from Lake Sharpe than was gained in the water received from Lake Oahe. There was a fairly consistent relation between the estimated weekly mean loss of zooplankton in water releases at Oahe and Big Bend dams in both years (Figs. 4 and 5); the correlation coefficient was 0.68 ( $P < 0.01$ ) for

1974 and 0.58 ( $P < 0.05$ ) for 1975. Because of the rapid water-exchange rates in Lake Sharpe, a real net loss of biomass would be expected.

The apparent increase in abundance of zooplankton in Lake Sharpe was a result of production within the impoundment. Known zooplankton production rates—in cladocerans for example (Hall 1964)—are sufficiently rapid at the prevailing summer water temperatures (June 1987) to permit substantial population increases in Lake Sharpe, given the observed retention times.

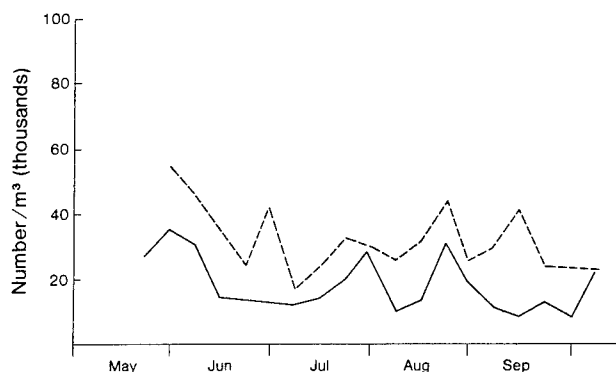


Fig. 4. Weekly mean density of zooplankton discharged from Lake Oahe (solid line) and from Lake Sharpe (broken line), May-October 1974.

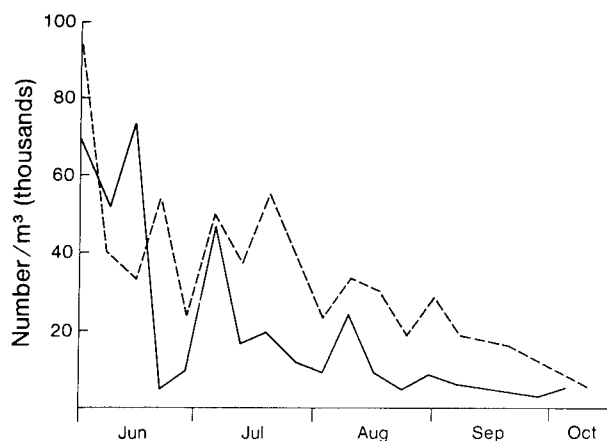


Fig. 5. Weekly mean density of zooplankton discharged from Lake Oahe (solid line) and from Lake Sharpe (broken line), June-October 1975.

### Ancillary Samples

Comparison of the mean catches of the paired No. 10 and No. 20 nets in mid-channel and cross-channel tows in the two tailwaters indicated greater density and biomass of plankton in the No. 20 net samples, together with increased representation of copepod nauplii, rotifers, protozoa, and phytoplankton. The mean density of zooplankters in the No. 20 net was double that of the No. 10 net in Oahe Dam tailwater and almost triple that of the No. 10 net in Big Bend Dam tailwater (Table 3). Differences in the AFDW's of the samples were small; on the average, the No. 10 net samples underestimated biomass exports by only about 14%. The disproportionate increase in numbers in the No. 20 net was attributable to the greater representation of nauplii and rotifers, as indicated by the lower mean weight per organism. A comparison of the mean density (no./m<sup>3</sup>) of nauplii and rotifers caught by the two nets at each location follows:

	Oahe tailwater		Big Bend tailwater	
Net	Nauplii	Rotifers	Nauplii	Rotifers
No. 10	267	0	304	0
No. 20	12,416	5	25,471	10,296

Obviously the density of nauplii was grossly underestimated by catches in the No. 10 nets. Few rotifers were collected in the Oahe Dam tailwater; their low density reflects either a paucity in the waters of lower Lake Oahe or in the strata from which water was discharged. The principal genera

Table 3. Number and biomass of zooplankton collected in No. 10 and No. 20 plankton nets fished simultaneously in tailwaters of Oahe and Big Bend dams.

Tailwater and net	Density (no./m <sup>3</sup> )	Ash-free dry weight (mg/m <sup>3</sup> )	Mean weight per organism (g × 10 <sup>-6</sup> )
Oahe Dam			
No. 10	12,468	42.9	3.4
No. 20	26,166	46.2	1.8
Big Bend Dam			
No. 10	24,068	91.6	3.8
No. 20	71,175	110.8	1.6

Table 4. Percent composition of crustacean zooplankton captured by different nets in tailwaters of Oahe and Big Bend dams, June-October 1975.

Tailwater and net	Calanoids	Cyclopods	Cladocerans
Oahe Dam			
No. 10	54.1	24.5	21.3
No. 20	50.6	30.5	18.9
Big Bend Dam			
No. 10	40.9	25.9	33.2
No. 20	40.0	32.3	27.7

of rotifers captured in both tailwaters were *Brachionus*, *Conochilus*, *Kellicottia*, and *Polyarthra*. *Keratella* and *Trichotria* were captured only in Oahe Dam tailwater.

There were no significant differences in the percentage composition of the crustacean zooplankton groups captured by the No. 10 and No. 20 nets in either tailwater (Table 4).

### Zooplankton Mortality

Ruptured exoskeletons, miscellaneous body parts, and pieces of zooplankton were present in many of the samples taken in the tailwaters, especially in those collected during high water releases. Moreover, on a number of occasions, masses of cladocerans were seen trapped in the surface film and floating on the water surface behind riprap that formed side eddies in Oahe Dam tailwater. Some zooplankters were thus destroyed while passing through the turbines. However, we did not attempt to count the parts to yield whole-organisms estimates, nor were they separated when AFDW was determined.

### Phytoplankton

Phytoplankton numerically dominated samples collected with the No. 20 net. Diatoms accounted for 91% of the total (14 cells per liter) in Oahe Dam tailwater and 99% of the total (2,302 cells per liter) in Big Bend Dam tailwater. The most common genera were *Rhoicosphenia* and *Asterionella* in Oahe Dam tailwater and *Asterionella*, *Fragilaria*, and *Tribonema* in Big Bend Dam tailwater.

### *Ichthyoplankton*

No fish eggs or larvae were observed in the Miller sampler collections in the tailwaters of either Oahe Dam or Big Bend Dam, and none were taken in the 0.5-m net samples in the Oahe Dam tailwater. However, a total of 673 larvae, representing at least 10 species, were captured at Big Bend Dam during the 2 sampling years with the 0.5-m nets towed in the forebay. In addition, 145 fish eggs were taken in 1975 (none in 1974). Most of the specimens were captured in surface and middepth tows. The freshwater drum (*Aplodinotus grunniens*) was by far the most common species in the catches in both years (Table 5). Only three other forms, common carp (*Cyprinus carpio*), buffaloes (*Ictiobus* sp.) and yellow perch (*Perca flavescens*), were caught in appreciable numbers.

The increased numbers of larvae captured in 1975 may have been a result of higher sustained seasonal water releases through Big Bend Dam (June 1987), which could have removed greater numbers of fish eggs and larvae from nursery areas. However, the possibility that spawning conditions were more favorable in 1975 cannot be entirely discounted, in spite of the generally lower abundance of young-of-the-year fishes in 1975 reported by Beckman (1987).

Estimated losses of larval fish from Lake Sharpe, based on volume of water released and capture of larval fish (no./m<sup>3</sup>) in sampling nets, are indicated here for the 3 months when these losses were highest:

Month	Total no. (millions) discharged	
	1974	1975
June	5.8	43.1
July	30.1	52.5
August	9.7	5.3
Total	45.6	101.0

Although we demonstrated that large numbers of fish eggs and larvae were discharged through Big Bend Dam, the overall effect of such losses on the fish populations in Lake Sharpe is unknown.

### *Unanswered Questions*

Little is conclusively known of the effects of high water releases on the reservoir biota. However, zooplankton in particular appeared to be vulnerable to community displacement as a result of entrainment in reservoir discharges and of mortality during passage through the turbines at high water release rates. The crustacean zooplankton is a basic food source of all larval fishes, and of some species throughout life. Thus a water-management regimen that affords opportunity for reaching maximum standing crops of zooplankton is of prime importance to the maintenance and well-being of fish populations in the reservoir.

Little insight into the effects of peaking water releases on the dynamics of reservoir plankton populations was obtained. The data indicated that

Table 5. Percent composition of 673 larval fish collected in forebay of Big Bend Dam, 1974-75.

Taxon	Year and (in parentheses) total no.	
	1974 (165)	1975 (508)
Freshwater drum ( <i>Aplodinotus grunniens</i> )	82	64
Common carp ( <i>Cyprinus carpio</i> )	7	3
Buffaloes ( <i>Ictiobus</i> sp.)	2	15
Emerald shiner ( <i>Notropis atherinoides</i> )	1	3
Yellow perch ( <i>Perca flavescens</i> )	1	12
Others <sup>a</sup>	7	3

<sup>a</sup>Gizzard shad (*Dorosoma cepedianum*), burbot (*Lota lota*), white bass (*Morone chrysops*), crappies (*Pomoxis* sp.), and Iowa darter (*Etheostoma exile*).

a large biomass of crustacean zooplankton was lost from Lake Sharpe and, concomitantly, imported from Lake Oahe. Export losses were seemingly largely compensated for by importation and by production in the reservoir; however, it is unknown how this transfer and production affected impoundment fish populations. In addition, the effects of passage of zooplankton through the turbines is unknown. The observation of body fragments of various organisms in the net samples and entrapment in the surface film of the tailwaters implies some loss. Nevertheless, most organisms in the net samples were intact and seemingly uninjured. Culture studies would be required to determine what portion of the zooplankton survives transport through the turbines, and whether there is a relation between water-discharge rate and mortality. The effects of passage and water-discharge rates on the reproductive activities and growth of zooplankton, and the extent to which community breakdown and displacement occur as a result of peaking, are essentially unknown. Although our data imply loss of large numbers of fish eggs and larvae, nothing is known about their ultimate fate, nor about the effect of the loss on reservoir fish populations.

Information on these various interactions would provide both fishery and water managers with a better understanding of the biological consequences of water-management practices in large impoundment systems.

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## Relative Abundance and Distribution of Young-of-the-year Fishes and Minnows in Lake Sharpe, South Dakota, 1967-1975

by

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### Abstract

The apparent abundance and distribution of young-of-the-year fishes and minnows in Lake Sharpe, South Dakota, were determined from weekly or biweekly catches with a bag seine and bottom trawl in summer (June-September), 1967-75. Trends in catches with the two types of gear were usually similar, although the seine was more effective for catching most species. Abundance was usually highest in a single 400-ha backwater area, Hipple Lake (which alone accounted for about 40% of the total catch of nearly 347,000 fish during the 9-year period), and in the middle third of the reservoir. Catches were highest in midsummer for most species in all areas except the upper reservoir, where catches peaked in late summer, possibly due to upstream migration of young fish. Gizzard shad (*Dorosoma cepedianum*) and yellow perch (*Perca flavescens*) accounted for more than 80% of the 9-year seine catch, and gizzard shad, yellow perch, black crappies (*Pomoxis nigromaculatus*), and white crappies (*P. annularis*) accounted for 90% of the trawl catch. Catches of the principal species were highest in 1968, and were lower and relatively stable from 1972 to 1975. During 1971-75, catches of young-of-the-year walleyes (*Stizostedion vitreum vitreum*), the primary game fish in Lake Sharpe, remained relatively stable; catches of freshwater drum (*Aplodinotus grunniens*), white bass (*Morone chrysops*), bigmouth buffalo (*Ictiobus cyprinellus*), and smallmouth buffalo (*I. bubalus*) increased; and catches of most other species decreased. Stocks of minnows and young-of-the-year fishes tended to stabilize after 1971. Except for walleyes, predator species were greatly reduced from earlier years, and most forage species had declined. Thus it appeared that the fish population structure in Lake Sharpe would continue to consist of a dominant predator (the walleye) supported by reduced populations of a variety of forage species.

The primary objectives of a study of the abundance and distribution of minnows and young-of-the-year (YOY) fishes in Lake Sharpe, South Dakota, in 1967-75 were to assess the annual reproductive success by species, delineate changes in spatial distribution, and relate variations in abundance to environmental changes during the early years of impoundment. The annual abun-

dance estimates of YOY provided useful information on the relative importance of various spawning and nursery areas and early-life survival, and facilitated interpretation of changes observed in adult stocks.

Lake Sharpe, a main-stem Missouri River reservoir in central South Dakota (Fig. 1), was formed by the closure of Big Bend Dam in 1963. At full operational pool, reached in December 1965, the reservoir was about 137 km long and had a surface area of 22,600 ha, and a maximum depth of 26 m; the water level was stable, fluctuating less than 0.8 m

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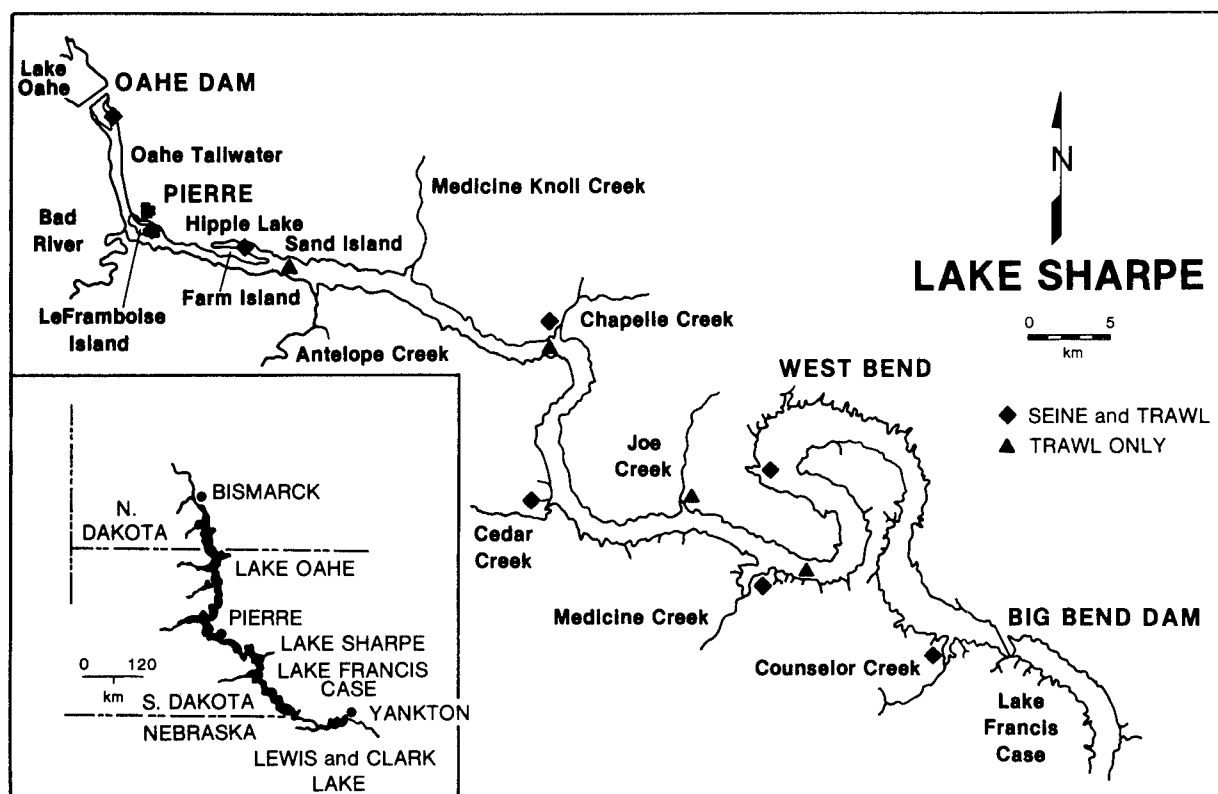


Fig. 1. Fish sampling locations in Lake Sharpe, 1967-75.

annually during 1967-75. Lake Sharpe has no permanent tributaries, and the principal water source is discharge through Oahe Dam. Runoff entering from the Bad River and several smaller intermittent tributaries occasionally accounted for heavy silt loads. Few large embayments are present, but one such area, Hipple Lake, in the upper third of Lake Sharpe, is a backwater cul-de-sac, formed by a causeway from Farm Island at the upper end and an outlet into Lake Sharpe proper (at the tip of Farm Island) at the lower end (Fig. 1). Hipple Lake is about 5 km long, has a maximum width of about 0.7 km, an area of about 400 ha, and a maximum depth of 4 m; the lower portion is bounded by large expanses of cattails (*Typha*) and other aquatic vegetation.

## Materials and Methods

Minnows and YOY fish were sampled with a bag seine (30.5 × 2.4 m; 6.4-mm bar mesh) and an otter

trawl (8.2 m; 19-mm bar mesh with a 6.4-mm mesh cod liner). A standard seine haul was made by extending the net perpendicular to the shore and towing it in a quarter circle back to shore. The duration of a standard bottom trawl haul was 10 min, at a constant engine speed. A sampling round of trawling and seining was completed in 1 and 2 days, respectively, weekly in 1967 and 1968 and biweekly in 1969-75, from late June to early September. All sampling was done during daylight. The average catch per unit of effort (C/f)—a standard seine or trawl haul—was accepted as a measure of fish abundance.

Seining was conducted at eight widely separated localities in the reservoir; six were in embayments, one on the main reservoir floodplain, and one adjacent to the main channel of the Oahe tailwater but out of the current (Fig. 1). Standard hauls were made at three sites within each sampling area on each collection date.

Trawl stations established at 12 sites throughout the reservoir represented the three principal habitat types (embayment, river channel, and

floodplain). Eight of the trawling sites were also seining stations (Fig. 1), enabling comparisons of catches with the two gears. For descriptive purposes the reservoir was divided into three 45-km sections. The two downstream seine and trawl stations (Counselor Creek and West Bend) were in the lower third; three seine and four nonchannel trawl stations (Medicine, Joe, Cedar, and Chapelle creeks) were in the middle third; and two seine and trawl stations (LeFramboise Island and Oahe tailwater) were in the upper third (Fig. 1). Hipple Lake, although located in the upper third, is considered separately because of its relative isolation and unique characteristics.

Fish were preserved in 10% formalin in the field and identified and counted in the laboratory. Random samples or complete catches of as many as 50 specimens of each species from individual collections were measured to the nearest millimeter, fork length. Young-of-the-year minnows were not separated from adults. Common and scientific names of the fishes collected are shown in Table 1.

## General Abundance and Distribution

Nearly 347,000 minnows and YOY fishes were collected during the study—about 270,000 by seine and 77,000 by trawl. Abundance and distribution trends of most species were usually better reflected by catches in the seine than by those in the trawl; exceptions were saugers, black crappies, white crappies, and freshwater drum (Table 2). Catches in both gears suggested roughly similar long-term trends in abundance for many species, although occasional wide differences occurred, and some species taken by one gear were not taken by the other.

The annual C/f for all species combined varied widely among years; it was highest in 1968 and lowest in 1972—more than 80% lower than in 1968—for both seine and trawl (Table 2). The catch in both gears remained relatively stable from 1973 to 1975, except that the trawl catch was 48% lower in 1975 than in 1974. The C/f's in seine and trawl in 1975 were only 26 and 20%, respectively, of those in the peak year of 1968.

Table 1. Common and scientific names of minnows and young-of-the-year fishes collected in Lake Sharpe, 1967-75.<sup>a</sup>

Family, genus, and species	Common name
Clupeidae	Herrings
<i>Dorosoma cepedianum</i>	gizzard shad
Hiodontidae	Mooneyes
<i>Hiodon alosoides</i>	goldeye
Salmonidae	Trouts
<i>Oncorhynchus nerka</i>	kokanee
<i>Salmo gairdneri</i>	rainbow trout
Osmeridae	Smelts
<i>Osmerus mordax</i>	rainbow smelt
Esocidae	Pikes
<i>Esox lucius</i>	northern pike
Cyprinidae	Carps and minnows
<i>Cyprinus carpio</i>	common carp
<i>Hybognathus hankinsoni</i>	brassy minnow
<i>Hybognathus nuchalis</i> and <i>H. placitus</i>	Mississippi and plains minnows
<i>Hybopsis gracilis</i>	flathead chub
<i>Notemigonus crysoleucas</i>	golden shiner
<i>Notropis atherinoides</i>	emerald shiner
<i>Notropis lutrensis</i>	red shiner
<i>Notropis topeka</i>	Topeka shiner
<i>Pimephales notatus</i> and <i>P. promelas</i>	bluntnose and fathead minnows
<i>Semotilus atromaculatus</i>	creek chub
Catostomidae	Suckers
<i>Carpionodes carpio</i>	river carpsucker
<i>Catostomus commersoni</i>	white sucker
<i>Cycleptus elongatus</i>	blue sucker

Table 1. *Continued.*

Family, genus, and species	Common name
<i>Ictiobus bubalus</i>	smallmouth buffalo
<i>Ictiobus cyprinellus</i>	bigmouth buffalo
<i>Moxostoma macrolepidotum</i>	shorthead redhorse
Ictaluridae	Bullhead catfishes
<i>Ictalurus melas</i>	black bullhead
<i>Ictalurus punctatus</i>	channel catfish
<i>Noturus flavus</i>	stonecat
Gadidae	Codfishes
<i>Lota lota</i>	burbot
Gasterosteidae	Sticklebacks
<i>Culaea inconstans</i>	brook stickleback
Percichthyidae	Temperate basses
<i>Morone chrysops</i>	white bass
Centrarchidae	Sunfishes
<i>Lepomis cyanellus</i>	green sunfish
<i>Lepomis humilis</i>	orangespotted sunfish
<i>Lepomis macrochirus</i>	bluegill
<i>Micropterus salmoides</i>	largemouth bass
<i>Pomoxis annularis</i>	white crappie
<i>Pomoxis nigromaculatus</i>	black crappie
Percidae	Perches
<i>Etheostoma exile</i>	Iowa darter
<i>Perca flavescens</i>	yellow perch
<i>Stizostedion canadense</i>	sauger
<i>Stizostedion vitreum vitreum</i>	walleye
Sciaenidae	Drums
<i>Aplodinotus grunniens</i>	freshwater drum

<sup>a</sup>Fish names from Robins (1980).

A total of 41 species were caught during the study—38 by seine and 35 by trawl (Table 2). Yearly maximum and minimum numbers of species were 31 (1968) and 24 (1971 and 1974) by seine and 23 (1973 and 1974) and 14 (1971) by trawl. About 90% of the total 9-year catch was composed of three species for the seine (gizzard shad, yellow perch, and emerald shiner) and four species for the trawl (gizzard shad, yellow perch, black crappie, and white crappie); roughly 76% of the total catch in both gears combined consisted of gizzard shad and yellow perch (Table 3).

Variety and abundance of fish in catches were usually highest in Hipple Lake (which alone accounted for nearly 40% of the total 9-year catch) and in midreservoir. One exception was high abundance at the lowermost reservoir station (Counselor

Creek, Table 4), where a single trawl sample taken in 1968 accounted for more than 60% of the total 9-year catch at that station. Overall, seine and trawl catches in Hipple Lake were roughly 2 to nearly 3 times higher than catches in the next most productive area of the reservoir (Tables 4 and 5).

Catches decreased overall from 1968 to 1970, and there were changes in distribution. The lower reservoir accounted for nearly 35% of the total seine catch of YOY fish in 1968; catches there subsequently declined, and accounted for only 8–11% of the total in 1973–75. In contrast, catches of YOY in midreservoir increased from a low of 18% of the total catch in 1968 to more than 50% in 1972–75. Catches in Hipple Lake declined from 40–50% of the annual total in 1968–71 to 15–25% in 1972–75. Abundance of YOY in the upper reservoir was low

Table 2. Average catch of minnows and young-of-the-year fishes per seine haul and (in italics) per trawl haul in Lake Sharpe, 1967-75, arranged in general order of abundance or importance of the family in the fish community (*T* = trace; dash = nil).

Family and species	Year of collection								
	1967	1968	1969	1970	1971	1972	1973	1974	1975
Herrings									
Gizzard shad	46.4 <i>33.6</i>	188.3 <i>96.9</i>	175.6 <i>57.7</i>	117.9 <i>55.0</i>	102.8 <i>25.2</i>	40.3 <i>30.0</i>	91.3 <i>25.5</i>	65.9 <i>68.8</i>	51.5 <i>34.6</i>
Perches									
Yellow perch	58.3 <i>62.6</i>	150.9 <i>153.1</i>	76.6 <i>4.1</i>	19.9 <i>18.9</i>	8.6 <i>8.9</i>	20.5 <i>7.2</i>	20.1 <i>37.2</i>	32.6 <i>20.1</i>	24.4 <i>10.1</i>
Walleye	0.9 <i>2.8</i>	7.6 <i>11.7</i>	5.5 <i>7.0</i>	2.9 <i>14.2</i>	2.3 <i>6.7</i>	3.2 <i>7.0</i>	2.2 <i>7.9</i>	2.5 <i>5.8</i>	2.7 <i>8.6</i>
Sauger	0.5 <i>2.5</i>	1.3 <i>0.7</i>	0.3 <i>0.6</i>	0.4 <i>2.3</i>	0.1 <i>T</i>	0.1 <i>0.1</i>	<i>T</i> <i>0.1</i>	0.2 <i>0.2</i>	0.1 <i>0.1</i>
Iowa darter	<i>T</i> —	0.1 —	— —	— <i>T</i>	— —	<i>T</i> —	<i>T</i> <i>0.1</i>	<i>T</i> <i>0.1</i>	0.3 <i>0.5</i>
Cyprinids									
Emerald shiner	15.6 —	26.9 <i>T</i>	21.4 <i>T</i>	60.0 <i>0.1</i>	33.6 <i>T</i>	3.3 —	0.6 —	1.2 <i>T</i>	4.1 <i>T</i>
Red shiner	2.4 —	1.8 —	0.6 —	1.5 —	0.5 —	0.6 —	1.0 —	0.9 <i>T</i>	1.2 —
Topeka shiner	0.3 —	1.6 —	0.9 —	0.7 —	1.0 —	2.5 —	0.8 <i>T</i>	0.5 —	0.7 —
<i>Pimephales</i> sp.	0.3 —	1.2 <i>T</i>	0.4 <i>T</i>	0.1 <i>T</i>	0.1 —	1.0 <i>T</i>	0.1 <i>T</i>	<i>T</i> —	0.8 <i>T</i>
<i>Hybognathus</i> sp.	2.7 —	1.3 —	0.3 —	1.2 —	0.6 —	0.5 —	1.7 <i>T</i>	0.1 <i>T</i>	2.3 <i>T</i>
Flathead chub	<i>T</i> —	<i>T</i> —	<i>T</i> —	<i>T</i> —	0.1 <i>T</i>	0.4 —	0.2 <i>T</i>	0.2 —	— —
Golden shiner	0.2 —	0.1 <i>T</i>	0.1 <i>T</i>	<i>T</i> —	— —	<i>T</i> —	— —	— —	<i>T</i> —
Common carp	0.1 —	0.1 —	<i>T</i> <i>T</i>	0.1 —	— —	0.1 <i>T</i>	0.1 <i>0.5</i>	0.1 <i>0.5</i>	0.1 <i>0.4</i>
Sunfishes									
Black crappie	1.2 <i>4.9</i>	1.8 <i>6.8</i>	0.1 <i>2.4</i>	8.8 <i>86.2</i>	1.1 <i>16.8</i>	0.2 <i>6.5</i>	0.2 <i>40.6</i>	0.1 <i>15.2</i>	0.1 <i>3.5</i>
White crappie	2.2 <i>39.7</i>	2.2 <i>63.9</i>	0.1 <i>8.5</i>	1.0 <i>33.6</i>	0.1 <i>24.1</i>	<i>T</i> <i>0.6</i>	<i>T</i> <i>7.6</i>	0.1 <i>13.6</i>	<i>T</i> <i>0.8</i>
Largemouth bass	0.3 <i>T</i>	0.1 <i>T</i>	<i>T</i> <i>T</i>	0.1 <i>0.1</i>	0.1 —	0.1 —	0.4 —	0.1 <i>T</i>	<i>T</i> <i>T</i>
Bluegill	0.1 <i>0.1</i>	<i>T</i> —	0.3 <i>0.1</i>	0.1 <i>0.4</i>	0.1 <i>0.1</i>	— —	<i>T</i> <i>0.1</i>	— <i>T</i>	— —
Orangespotted sunfish	<i>T</i> —	<i>T</i> —	— <i>T</i>	<i>T</i> <i>0.2</i>	<i>T</i> <i>T</i>	<i>T</i> <i>T</i>	<i>T</i> <i>0.5</i>	<i>T</i> <i>0.4</i>	0.3 <i>0.2</i>
Green sunfish	<i>T</i> —	<i>T</i> —	<i>T</i> —	<i>T</i> —	<i>T</i> —	<i>T</i> —	— —	— —	<i>T</i> <i>T</i>
Suckers									
Bigmouth buffalo	0.1 <i>0.1</i>	0.2 —	0.3 —	0.5 <i>0.1</i>	0.1 —	1.7 <i>0.1</i>	1.3 <i>0.7</i>	1.6 <i>0.5</i>	3.7 <i>0.8</i>
Smallmouth buffalo	0.5 <i>0.2</i>	0.2 —	<i>T</i> —	0.1 <i>T</i>	<i>T</i> —	0.5 <i>0.1</i>	0.3 <i>0.1</i>	1.2 <i>0.1</i>	2.3 <i>0.2</i>
White sucker	<i>T</i> —	0.2 <i>T</i>	0.7 <i>0.1</i>	0.2 <i>0.1</i>	0.1 <i>0.1</i>	0.4 <i>T</i>	0.2 <i>0.1</i>	0.3 <i>0.1</i>	0.7 <i>T</i>
River carpsucker	0.2 —	0.1 —	0.1 <i>0.1</i>	<i>T</i> <i>T</i>	0.3 —	0.2 <i>T</i>	0.1 —	0.3 <i>T</i>	0.4 <i>T</i>
Shorthead redhorse	0.1 <i>T</i>	0.6 <i>T</i>	0.2 <i>T</i>	0.1 —	— —	0.2 <i>T</i>	0.2 —	<i>T</i> <i>T</i>	0.1 —

Table 2. *Continued.*

Family and species	Year of collection								
	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drums									
Freshwater drum	0.2 10.4	0.2 2.3	0.1 0.4	0.5 1.3	0.2 0.4	0.2 1.1	1.6 4.4	1.7 4.7	1.5 4.8
Temperate basses									
White bass	2.0 5.2	0.2 0.2	0.7 0.1	0.3 0.8	0.2 0.1	0.4 0.1	0.3 0.9	2.3 1.3	3.5 3.5
Mooneyes									
Goldeye	3.3 1.4	0.3 0.3	— —	T —	0.3 0.1	T T	0.2 0.1	— —	0.1 T
Bullhead catfishes									
Channel catfish	T 0.4	T T	— T	— T	— —	— —	— T	— —	T —
Other species <sup>a</sup>	T —	T —	0.4 —	0.1 —	T —	T —	T T	0.3 T	0.2 0.3
Catch data									
No. of hauls	216 34	240 60	120 60	144 71	144 49	144 72	144 72	144 72	144 72
Average no. fish/haul	139 164	388 336	285 81	217 213	152 83	76 53	123 127	112 131	101 68
No. of species	30 15	31 16	29 19	28 19	24 14	29 17	26 23	24 23	29 22

<sup>a</sup>Includes the following species, taken only in the gears and years shown: kokanee, trawl, T (1973); rainbow trout, seine, 0.3 (1974), 0.2 (1975); rainbow smelt, trawl, 0.3 (1975); northern pike, seine, T (1968, 1969) and trawl, T (1973); brassy minnow, seine, 0.1 (1968, 1969) and T (1971, 1972); creek chub, seine, 0.3 (1969), T (1970); blue sucker, seine, T (1967, 1968, 1972, 1975); black bullhead, seine, 0.9 (1967), T (1969, 1970); stonecat, seine, T (1969); burbot, trawl, T (1974); and brook stickleback, seine, T (1972, 1973, 1975) and trawl, T (1974).

in every year. The most significant change in the later years of the study was the greater abundance of gizzard shad in areas of previously low abundance.

Catches of YOY were highest in midsummer of most years in all areas except the two upper reser-

voir stations, where they were highest in late summer. Catches were low in early summer because the small fish escaped through the collection nets, and in late summer because the fish were probably large enough to avoid the nets or had moved out of the nursery areas. However, I assumed that this potential source of bias could be expected to operate about equally in the different years, and that it would not seriously impair the usefulness of the catch records for comparisons between and among years.

No significant differences in abundance were evident from seine catches between stations within embayments (upper, middle, lower embayment stations) during the study—probably because all of the embayments in Lake Sharpe were relatively small. Similar studies in Lake Oahe indicated that the number of species, as well as the abundance of most species, was generally highest in the upper stations of embayments (Beckman and Elrod 1971).

Trawl C/f at embayment stations was nearly 6 times that at floodplain stations and more than 37 times that at river channel stations (Table 4). Trawl

Table 3. *Species composition (percent) of total catch of minnows and young-of-the-year fishes with seine and trawl in Lake Sharpe, 1967-75.*

Species	Seine	Trawl	Catch total
Gizzard shad	53	35	49
Yellow perch	28	24	27
Emerald shiner	10	—	8
Black crappie	—	16	4
White crappie	—	14	3
Walleye	2	6	3
Other <sup>a</sup>	7	5	6

<sup>a</sup>A total of 32 other species were taken with the seine and 29 with the trawl (see Table 2).

Table 4. *Mean catch of minnows and young-of-the-year fishes of all species per unit of trawling effort, by habitat and sampling station, in Lake Sharpe, 1967-75.*

Location	Mean catch per trawl haul
Embayments	
Counselor Creek	295
Medicine Creek	153
Cedar Creek	120
Hipple Lake	839
LeFramboise Island	90
Mean	299
Floodplain	
West Bend	63
Joe Creek	48
Chapelle Creek	45
Mean	52
River channel	
Medicine Creek	14
Chapelle Creek	2
Sand Island	7
Oahe tailwater	9
Mean	8
Mean (areas combined)	140

Table 5. *Mean catch of minnows and young-of-the-year fishes of all species per unit of seining effort, by area, in Lake Sharpe, 1967-75.*

Location and area	Mean catch per seine haul
Lower reservoir	
Counselor Creek	134
West Bend	128
Middle reservoir	
Medicine Creek	217
Cedar Creek	146
Chapelle Creek	147
Hipple Lake	490
Upper reservoir	
LeFramboise Island	109
Oahe tailwater	45
Mean	177

catches from embayments ranged from 80 to 95% of the total annual catch, whereas catches from floodplain and river channel stations never accounted for more than 18 and 6% of the annual catch, respectively; species diversity was also greatest in embayments. General trends in abundance and distribution indicated by trawl catches were similar to those indicated by seine catches, although not always as marked.

## Fishes Collected

The 41 species of minnows and YOY fishes collected in Lake Sharpe in 1967-75 included 14 families (Table 1), of which 5 were best represented in the catch, in either numbers of fish or numbers of species (or both): herrings (represented by the gizzard shad), perches, sunfishes, cyprinids (minnows and the common carp), and suckers. Each of these families is discussed here, and summary statements are offered for the other families and species in the catch.

### Herrings

The herring family was represented only by the gizzard shad, which was usually the most abundant species captured by trawls and seines. The highest average annual catches were 188 per seine haul and 97 per trawl haul in 1968, and the lowest were 40 per seine haul in 1972 and about 25 per trawl haul in 1971 and 1973 (Table 2). Seine catches decreased annually from 1968 to 1972, rose sharply in 1973, and again declined in 1974 and 1975. Trawl catches decreased annually during 1968-71 and thereafter remained relatively stable (except for an increase in 1974). Although YOY gizzard shad declined in abundance during 1967-75, the percent of the annual catch contributed by them generally increased (Table 6). They contributed 33 to 74% (average 56%) of the total seine catch during 1967-75. Trawl catches of YOY ranged from 20 to 71% of the total catch during different years and averaged 40%. Gizzard shad accounted for 49% of the 9-year combined catch of YOY in seines and trawls (Table 3).

Gizzard shad distribution was relatively stable during the early years of the study, but subtle changes occurred in later years. More than 55% of all YOY taken by seine and trawl during the 9-year study came from Hipple Lake; the largest numbers were collected in 1968. In 6 of 9 years, average

Table 6. *Annual percentage composition of predominant species in seine and trawl catches in Lake Sharpe, 1967-75.*

Gear and species	Year									Annual mean
	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Seine										
Gizzard shad	33	49	62	54	67	53	74	59	51	56
Emerald shiner	11	7	8	28	22	4	<1	1	4	10
Yellow perch	42	39	27	9	6	27	16	29	24	24
Walleye	<1	2	2	1	1	4	2	2	3	2
Total	87	96	98	92	96	88	92	91	82	91
Trawl										
Gizzard shad	21	29	71	26	30	57	20	52	50	40
White crappie	24	19	11	16	29	1	6	10	1	13
Black crappie	3	2	3	40	20	12	32	12	5	14
Yellow perch	38	46	5	9	11	14	29	15	15	20
Walleye	2	3	9	7	8	13	6	4	13	7
Total	88	99	98	99	98	97	93	93	84	94

catches of YOY in seines were more than 6 times higher in Hipple Lake than in any other locality. The annual C/f with seines in Hipple Lake ranged from 64 to 1,187, and 91% of the total gizzard shad catch came from this station in 1968 (Table 7). Abundance was highest in midreservoir in 1973 and in the upper

reservoir in 1974. In the upper reservoir, 96% of the total catch was taken on or after July 30, suggesting a late-summer upstream migration rather than the presence there of an important spawning and nursery area. The lower reservoir never accounted for more than 12% of the annual catch. The C/f for

Table 7. *Annual catch of young-of-the-year gizzard shad per unit of effort, by gear and area, in Lake Sharpe, 1967-75 (percent of total catch of YOY in all areas combined is shown in parentheses).<sup>a</sup>*

Gear and area	Year									Area mean
	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Seine										
Lower reservoir	1	17	5	15	22	18	25	16	9	14
	(T)	(1)	(T)	(2)	(3)	(12)	(7)	(6)	(3)	(4)
Middle reservoir	70	86	143	115	82	71	138	68	64	93
	(38)	(7)	(13)	(17)	(13)	(45)	(38)	(26)	(25)	(25)
Hipple Lake	87	1,187	952	542	525	64	126	72	166	413
	(47)	(91)	(86)	(79)	(83)	(41)	(35)	(27)	(64)	(61)
Upper reservoir	27	14	6	13	3	3	71	110	19	30
	(15)	(1)	(1)	(2)	(T)	(2)	(20)	(41)	(7)	(10)
Trawl										
Embayment	79	216	131	110	43	70	55	133	69	101
	(94)	(89)	(91)	(74)	(61)	(96)	(85)	(72)	(75)	(82)
Floodplain	5	27	11	34	27	3	9	52	22	21
	(6)	(11)	(8)	(23)	(39)	(4)	(14)	(28)	(24)	(17)
Channel	T	T	2	4	T	T	1	1	1	1
	(T)	(T)	(1)	(3)	(T)	(T)	(2)	(T)	(1)	(1)

<sup>a</sup>T = trace (less than 0.5 fish or 0.5%).

gizzard shad with the trawl was highest in the embayments and lowest in the river channel (Table 7). In late summer, large schools were frequently observed on the surface of the main reservoir, seemingly migrating upstream. Annual trawl catches from embayments made up 61 to 96% of the total catch and averaged 82%.

Despite the high abundance of YOY gizzard shad in the catch throughout the 9-year study, winter mortality was extremely high in every year, and the species appeared destined to survive in only small numbers or disappear (June 1987).

### Perches

The perch family was strongly represented in Lake Sharpe by YOY yellow perch, walleyes, and saugers.

The yellow perch was the second most abundant species caught in the reservoir, accounting for more than one-fourth of the total 9-year catch (Table 3). Abundance was highest in the early years of impoundment; perch dominated the seine catches in 1967 and the trawl catches in both 1967 and 1968 (Tables 2 and 6). The seine was somewhat more effective than the trawl for collecting this species.

Annual C/f for both sampling methods was highest in 1968 (151 for seines and 153 for trawls). Percentage of yellow perch in the annual seine catch decreased each year from 1967 to 1971, increased in 1972, and remained relatively stable thereafter. Trends in percentage of yellow perch in annual trawl catches were similar. In general, the changes in abundance of yellow perch in Lake Sharpe over time—generally decreases—were similar to those in other Missouri River reservoirs (Nelson and Walburg 1977).

Catches of yellow perch in seines were usually highest in the lower and middle reservoir (Table 8). Maximum C/f at stations in the lower reservoir was 730 per seine haul in 1967 at West Bend and more than 1,700 per trawl haul in 1968 at Counselor Creek. In 1973, when abundance was highest in the upper reservoir, 94% were caught during the second half of the sampling season, indicating (as in gizzard shad) late-summer upstream movement rather than the presence of a significant spawning and nursery area in this section of the reservoir. Few yellow perch were taken from the upper-reservoir stations in any year during the early-summer sampling periods. This observation agrees with that of Nelson (1980) in upstream Lake Oahe, where he noted

Table 8. Annual average catch of young-of-the-year yellow perch per seine haul and per trawl haul in different areas of Lake Sharpe, 1967-75 (percentage of total annual catch in parentheses).<sup>a</sup>

Gear and area	Year									Area mean
	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Seine										
Lower reservoir	166	453	124	17	13	44	11	13	22	96
	(69)	(75)	(50)	(23)	(42)	(57)	(15)	(12)	(25)	(41)
Middle reservoir	33	62	120	33	11	19	25	62	39	45
	(14)	(10)	(49)	(46)	(36)	(25)	(34)	(59)	(46)	(35)
Hipple Lake	35	70	1	18	5	10	10	12	13	19
	(15)	(11)	(1)	(25)	(17)	(13)	(14)	(11)	(15)	(14)
Upper reservoir	5	23	1	4	2	4	27	18	11	11
	(2)	(4)	(1)	(5)	(5)	(5)	(37)	(17)	(13)	(10)
Trawl										
Embayment	116	352	7	43	16	15	58	37	14	73
	(68)	(94)	(62)	(89)	(68)	(83)	(53)	(66)	(44)	(70)
Floodplain	51	23	4	5	7	3	44	18	15	19
	(30)	(6)	(34)	(10)	(31)	(16)	(40)	(33)	(49)	(28)
Channel	4	1	1	T	T	T	7	1	2	2
	(2)	(T)	(4)	(1)	(1)	(1)	(6)	(1)	(7)	(3)

<sup>a</sup>T = trace (less than 0.5 fish or 0.5%).

that yellow perch larvae were never collected in riverlike areas. Abundance of YOY yellow perch in Lake Sharpe increased in the upper reservoir during the last 3 years of the study (1973-75), when they accounted for 13 to 37% of the total annual seine catch (Table 8).

Embayments were the most important spawning and nursery areas of yellow perch; in only 1 year (1975) was the trawl C/f marginally highest at the floodplain stations (Table 8). Mean annual C/f was about 4 and 36 times higher in embayments than at floodplain and channel stations, respectively. Percentage of annual catch from embayments was as high as 94% and averaged 70%. The highest annual trawl C/f from embayments was 352 in 1968, whereas the C/f from floodplain and channel stations never exceeded 51 and 7, respectively.

The walleye became the most important sport fish in Lake Sharpe in the late 1960's and remained so in the 1970's. The YOY were among the common species in the seine and trawl catches during this study (Tables 3 and 6). Walleyes established successful year classes in every year, and the abundance of adults increased markedly as the age of the impoundment increased (Elrod et al. 1987). Trends in catches of YOY with seines and trawls were roughly similar (Table 2). Although catches were greater in trawls than in seines, the greater con-

sistency of seine catches led Elrod et al. (1987) to choose them for estimating year-class strength of walleyes. Walleyes composed up to 4% (1972) of the annual seine catches and up to 13% (1972 and 1975) of the annual trawl catches (Table 6). The seine C/f was lowest in 1967, peaked in 1968, declined through 1971, and was relatively stable thereafter; the trawl C/f was lowest in 1967, increased to a peak in 1970, and then stabilized at about 50% of the peak level thereafter.

Catches of YOY walleyes were usually highest in midreservoir, although they were highest in the lower reservoir in seine catches in 1968 and 1972 (Table 9) and in trawl catches in 1971 (Table 10). Annual percentage of the total catch taken from midreservoir ranged from 29 to 73 for the seine and from 36 to 88 for the trawl. Mean annual trawl C/f for YOY walleyes was 2 and 14 times higher in embayments than in the floodplain or river channel stations, respectively (Table 9). Annual trawl C/f ranged from about 5 to 30 in embayments, from about 2 to 11 at floodplain stations, and from about 0.1 to 5 at channel stations. More than 90% of the total 9-year walleye catch with the seine and trawl at the upper reservoir station was made after July, and the percent of annual catches taken in this area after July ranged from 75 to 100. This pattern suggested (as in gizzard shad and yellow perch) a late-

Table 9. Annual mean catch of young-of-the-year walleyes per seine haul and per trawl haul in different areas of Lake Sharpe, 1967-75 (percent of total catch in parentheses).<sup>a</sup>

Gear and area	Year									Area mean
	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Seine										
Lower reservoir	0.2 (7)	12.9 (47)	2.8 (17)	1.0 (10)	2.3 (32)	4.8 (38)	0.6 (8)	2.2 (24)	2.6 (30)	3.3 (24)
Middle reservoir	1.9 (67)	9.3 (34)	12.3 (73)	5.6 (57)	4.3 (60)	3.6 (29)	3.6 (46)	4.0 (44)	5.0 (58)	5.5 (52)
Hipple Lake	0.7 (25)	3.6 (13)	1.5 (9)	1.9 (19)	0.4 (6)	3.2 (25)	2.0 (25)	2.0 (22)	0.6 (7)	1.8 (17)
Upper reservoir	T (1)	1.7 (6)	0.2 (1)	1.4 (14)	0.2 (3)	1.0 (8)	1.7 (22)	10.8 (9)	0.4 (5)	0.8 (8)
Trawl										
Embayment	5.1 (69)	23.0 (74)	11.1 (54)	30.2 (81)	13.7 (63)	13.4 (70)	10.6 (46)	6.8 (37)	16.8 (72)	14.5 (64)
Floodplain	1.8 (24)	7.3 (23)	9.2 (44)	5.4 (15)	7.7 (35)	5.8 (30)	7.9 (34)	11.2 (61)	6.3 (27)	7.0 (31)
Channel	0.5 (7)	0.9 (3)	0.4 (2)	1.6 (4)	0.4 (2)	T (T)	4.6 (20)	0.5 (3)	0.1 (T)	1.0 (4)

<sup>a</sup>T = trace (less than 0.5 fish or 0.5%).

summer upstream migration rather than the presence of a significant nursery area.

Saugers declined markedly in abundance after the early years of impoundment. Trawl catches were generally larger than seine catches. Sauger catches were highest in the trawl in 1967 and in the seine in 1968, and then declined to low levels after 1970 (Table 2). Most saugers were collected at midreservoir stations. Annual catches there were usually 2 to 5 times higher than in other areas. The upper reservoir was not an important nursery area: more than 95% of the saugers caught there in the seine and trawl were taken after July. Overall trawl C/f was 2.5 and 8.6 times higher in embayments than at floodplain and channel stations, respectively. Of all saugers taken, 75% came from embayments.

Iowa darters were rarely collected in Lake Sharpe, although they were represented in trace amounts in 7 of the 9 years of sampling. A single trawl haul in Oahe tailwater in 1975 yielded 63 of the total of 113 Iowa darters caught during the study.

### *Cyprinids*

Twelve species of cyprinids were represented in the catches from Lake Sharpe. Emerald shiners were by far the most abundant, being the third most abundant species taken in seines (following gizzard shad and yellow perch), although few were taken in trawls (largely because most could easily escape through the meshes). In similar studies on Lake Oahe, Beckman and Elrod (1971) and June (1976) found that annual catches of emerald shiners chiefly reflected the success of spawning and survival during the previous year, because YOY fish were not large enough to be captured by seine until after mid-August and most of the fish died before reaching age II. Fuchs (1967) found a similar situation in Lewis and Clark Lake; consequently no aging of Lake Sharpe fish was attempted. Mean annual C/f with seines during the first 5 years of the study (1967-71) was 13 times that during the last 4 years (1972-75). Annual C/f with seines varied markedly, ranging from less than 1 in 1973 to 60 in 1970 (Table 2). Percentage of emerald shiners in annual seine catches was highest in 1970 and 1971 (28 and 22, respectively) and lowest ( $< 1$ ) in 1973 (Table 6). Emerald shiners occurred throughout Lake Sharpe, although most were usually collected in Hipple Lake (Table 11). Kallemeyn and Novotny (1977) found that emerald shiners were abundant in nearly all habitat

types sampled in the Missouri River above and below Gavins Point Dam and in Lewis and Clark Lake.

Red shiners and Topeka shiners were relatively common in seine catches every year (Table 2). Annual seine C/f for both red shiners and Topeka shiners ranged from 0.3 to 2.5, but no abundance trend was evident for either species (Table 2). Catches of red shiners were usually highest in midreservoir and were consistently smaller in the lower reservoir and Hipple Lake. Catches of Topeka shiners were highest in the upper third of the reservoir and lowest in the lower third.

Two pairs of species—bluntnose and fathead minnows and silvery and plains minnows—were combined because it was difficult to separate the species of each pair with certainty after preservation. All four species were probably taken by seine in nearly every year, but the total catches were small (Table 2). Bluntnose and fathead minnows were widely distributed in the reservoir. Of the total silvery and plains minnows in the seine catch, 56% came from the upper (riverlike) reservoir and about 30% from midreservoir. Abundance was consistently lowest each year in the lower (lake-like) reservoir. The fairly widespread distribution in 1967 and 1968 was followed by a tendency toward upstream concentration as the years progressed. Bailey and Allum (1962) reported that the silvery minnow was more common than the plains minnow in the Missouri River. The populations of these primarily stream species will probably remain small, in response to the loss of the original river habitat.

Flathead chubs were taken by seine in most years, but relatively few were collected (Table 2); catches exceeded trace amounts only in 1971 to 1974. Nearly 90% of the total catch came from midreservoir and Hipple Lake. Bailey and Allum (1962) reported that this species was the dominant minnow in the turbid, flowing waters of the Missouri River. Golden shiners were rare or lacking in the catches after 1969; most were collected in the lower reservoir. A few brassy minnows were seined in the upper reservoir and a few creek chubs near midreservoir during the study.

Few young-of-the-year common carp were taken (Table 2). Of the total catch of 102, collections in 1973-75 accounted for 97. Smaller numbers were caught by seine than by trawl, but those taken by seine were widely distributed, whereas nearly all of those taken by trawl were from Hipple Lake.

Table 10. *Percentage of annual catch of young-of-the-year walleyes taken by trawl in the upper, middle, and lower third of Lake Sharpe, and Hipple Lake, 1967-75.*

Area	Year								
	1967	1968	1969	1970	1971	1972	1973	1974	1975
Lower reservoir	7	35	9	8	61	5	6	25	9
Middle reservoir	72	42	83	65	36	88	47	56	71
Hipple Lake	0	14	4	5	1	6	11	13	19
Upper reservoir	21	9	4	21	3	2	36	7	1

### Sunfishes

The sunfish family contributed six species to the catches in Lake Sharpe, but only the black crappie and white crappie were important members of the fish community.

Catches of black crappies were highest, in both seine and trawl, in 1970 (Table 2). Although abundance trends were similar through 1972 in both gears, catches were at least 4 times greater in trawls than in seines in every year. Black crappies composed 16% of the total 9-year trawl catch (Table 3). Seine catches of black crappies declined markedly after 1970; although trawl catches fluctuated annually, they also declined by 1975 (Table 2). Black crappies dominated the trawl catches in 1970 and 1973, accounting for 40 and 32%, respectively, of the annual catch (Table 6). Abundance is expected to continue to be low—as has occurred in other Missouri River main-stem reservoirs (June 1976; Walburg 1976, 1977). Of the total catch of 14,477 black crappies by seine and trawl, 95% came from Hipple Lake. The average annual trawl C/f was nearly 12 times greater in Hipple Lake

than in the rest of the reservoir. Annual C/f of black crappies with trawls in Hipple Lake ranged from nearly 23 in 1967 to more than 1,000 in 1979 and averaged about 260. Black crappies were uncommon in trawl catches at floodplain stations and rare at river channel stations.

White crappies were also more effectively sampled by trawl than by seine; catches in both gears were highest in 1967 and 1968 (Table 2). Mean annual catches declined greatly in seines after 1968 and in trawls after 1971. Highest C/f exceeded 60 with trawls (1968), but was only about 2 with seines (1967 and 1968). The white crappie was one of five dominant species in the trawl catches, accounting for 14% of the total 9-year catch (Table 3). Annual catches ranged from a low of 1% of the total trawl catch in 1972 and 1975 to 29% in 1971 (Table 6). About 90% of all white crappies taken during the study were from Hipple Lake. Highest seasonal trawl C/f in Hipple Lake was 750 (1968), which was at least 10-fold greater than catches in the area of next highest abundance. Only 69 white crappies were taken by trawling at floodplain and river channel stations and nearly 11,000 came from embayments.

Table 11. *Annual average catch of emerald shiners per seine haul in different areas of Lake Sharpe, 1967-75 (percentages of total annual catches in parentheses).*

Area	Year									Area mean
	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Lower reservoir	10.6 (17)	38.0 (34)	13.0 (11)	34.9 (12)	20.1 (12)	0.9 (7)	0.6 (22)	0.6 (10)	5.0 (28)	13.7 (17)
Middle reservoir	12.3 (20)	16.1 (14)	9.9 (8)	35.8 (13)	19.3 (12)	5.5 (44)	1.0 (37)	1.3 (22)	5.3 (30)	11.8 (22)
Hipple Lake	8.0 (13)	24.5 (22)	76.3 (65)	115.9 (41)	71.6 (44)	3.6 (29)	0.7 (26)	3.8 (63)	5.3 (30)	34.4 (37)
Upper reservoir	31.5 (50)	33.1 (30)	18.7 (16)	93.6 (33)	50.0 (31)	2.4 (19)	0.4 (15)	0.3 (5)	2.2 (12)	25.8 (23)

Largemouth bass were not native to the Missouri River basin of South Dakota (Bailey and Allum 1962), but extensive stocking in ponds of the drainage may have afforded a source of introduction into Lake Sharpe. The species was taken in small numbers in every year but never exceeded 0.4 per seine haul (Table 2). About 62% of the total seine and trawl catch of 217 was made at a midreservoir station (Medicine Creek) and Hipple Lake.

Other sunfishes taken in small numbers were bluegills, orangespotted sunfish, and green sunfish. Catches of bluegills were low in every year and nil in 1972 and 1975 (Table 2). A midreservoir station (Medicine Creek) and Hipple Lake accounted for 88% of the total catch of 154. Because bluegill populations have not developed in other Missouri River reservoirs, I expect their abundance in Lake Sharpe to remain low. Catches of orangespotted sunfish were low in every year, but most were taken in 1973-75. All but 20 of the 164 caught were taken from Hipple Lake and the midreservoir localities. Of the fish caught in trawls, 93% came from embayments and none from river channel stations. Green sunfish were taken in most years but catches were always small (Table 2). All were caught in the upper two-thirds of the reservoir.

### *Suckers*

The sucker family was represented by six species in the catches from Lake Sharpe, but none were abundant. Rather, they ranged from common for bigmouth buffalo (especially in the later years of the study) to rare for the blue sucker (total of only six collected, divided among 4 of the 9 years of the study).

Bigmouth buffaloes were most common in seine and trawl catches during 1972-75 (Table 2). Mean annual seine C/f was nearly 9 times larger during these years than during 1967-71. The species was lacking or uncommon in the trawl catches from 1967 to 1972 but increased markedly in 1973-75 (Table 2). Of the total caught in seine and trawl, 86% were taken during 1972-75. Distribution of bigmouth buffaloes was variable and widespread in most years. Seine catches were highest at a single lower reservoir station (West Bend) in every year from 1967 to 1972, and catches there accounted for more than 57% of the 6-year catch.

During 1973-75, more than 57% of the bigmouth buffaloes taken by seine came from midreservoir (Chapelle Creek). Relatively few were taken by trawl, and most of these were from Hipple Lake.

Smallmouth buffaloes were generally less abundant than bigmouth buffaloes, although abundance trends were similar (Table 2). More than 75% of the total seine and trawl catches of smallmouth buffaloes were taken during 1972-75. In 1967-71, nearly 80% of the smallmouth buffaloes taken by seine were from Hipple Lake, whereas in 1972-75, more than 80% came from midreservoir stations. Hipple Lake and Cedar Creek embayment accounted for about 75% of the small catch in trawls.

The white sucker, river carpsucker, and short-head redhorse contributed little to the total catch of YOY in Lake Sharpe. The few white suckers caught each year were usually taken in seines. Most were collected in 1969 and 1975 (Table 2). Nearly 50% of the total catch came from the upper reservoir, and about 35% from midreservoir. The river carpsucker, typically a riverine species, was taken by seine each year, but was never abundant. It was collected mainly from Hipple Lake and the midreservoir localities. The shorthead redhorse was more common in seine catches than in trawl catches and was collected in every year except 1971; the catch was about evenly divided between Hipple Lake and the upper and middle sections of the reservoir.

### *Other Fishes*

Only four other families—three represented by a single species—appeared in even moderate numbers in the Lake Sharpe catches (Table 2): drums (freshwater drum), temperate basses (white bass), mooneyes (goldeye), and bullhead catfishes (three species).

The freshwater drum was not a major species in Lake Sharpe, although it was taken every year with both seines and trawls. Catch per unit of effort was consistently higher with the trawl than with the seine; except for low seine catches in 1967, trends were similar. The annual trawl C/f was highest in 1967 and lowest in 1969 and 1971; abundance rose markedly during 1973-75 (Table 2). Mean annual C/f was about 7 times higher for the seine and 5 times higher for the trawl during the last 3 years of the study (1973-75) than in the

previous 5 (1968–72). Distribution was variable, although some basic trends were evident. Hipple Lake accounted for 43% of the total catch. Catches were relatively high in midreservoir and relatively low in the lower and upper reservoir. Except for Hipple Lake, trawl C/f was higher in the river channel than in the embayments or floodplain.

Abundance trends for white bass were similar in the seine and trawl. Catches were relatively high in 1967, relatively low from 1968 to 1973, and high again in 1974 and 1975 (Table 2). Annual distribution was variable, although catches were usually highest in midreservoir, accounting for 55% of the total seine and trawl catch; the rest were about equally divided between the other areas. In Hipple Lake, mean annual trawl C/f for white bass was more than 23 times higher in the last 3 years of sampling than in the first 6 years, whereas seine catches were high only in 1975. Nearly all fish caught in the upper reservoir were taken after the first week in August. Overall C/f for trawls was twice as high in embayments as in floodplain localities, and the species was rarely taken in the river channel.

Goldeyes were most common in seine and trawl catches in 1967, when nearly 80% of the 9-year catch was taken (Table 2). Seining was more effective than trawling for capturing YOY. After 1968, goldeye abundance declined to low levels and in several years none were collected. Nearly 90% of the goldeyes were captured in midreservoir stations. In the upper reservoir, the species was never taken by trawling and in only 1 year (1975) by seining. Trawl catches in embayments were about 3 times higher than in the floodplain and 12 times higher than in the river channel.

Channel catfish were rarely taken with either seine or trawl (Table 2). In view of their shelter-seeking tendencies, they were probably not sampled in proportion to their true abundance. Elrod (1974) reported that the channel catfish was one of the more abundant species in gill-net samples from Lake Sharpe. He further stated that the population level remained about the same during the first 8 years of impoundment and that the presence of fish of the 1964–1969 year classes indicated successful reproduction after impoundment. Two other catfishes—the stonecat and the black bullhead—were rare in the catches. Only one stonecat was taken during the 9-year study, and black bullheads were collected in only 2 years.

Fishes taken only rarely in Lake Sharpe are shown in Table 2 (footnote); several of these are exotic. The South Dakota Department of Game, Fish and Parks introduced kokanees into upstream Lake Oahe in 1970–72 and 1974, and rainbow trout into Lake Oahe tailwater in 1974 and 1975. Rainbow smelt, collected only in 1975, originated from plantings in upstream Lake Sakakawea by the North Dakota Department of Fish and Game in 1971. They soon spread to all of the lower Missouri River reservoirs (Oahe, Sharpe, Francis Case, and Lewis and Clark). The species was seemingly not strongly established in Lake Sharpe at the end of the present study; a total of only 22 were caught (at two midreservoir stations and Hipple Lake) in 1975.<sup>2</sup>

Only four YOY northern pike—long abundant as adults in Lake Oahe and abundant in Lake Sharpe in 1964–66—were caught during the present study. Three were taken by seine (one in 1968 and two in 1969) at a midreservoir station (Cedar Creek) and one was taken by trawl in 1973 in Hipple Lake.

## Discussion

The formation of Lake Sharpe initially flooded vast areas of prairie vegetation, providing ideal spawning and nursery habitat for many warm-water fish species. However, extended inundation and wave action destroyed shore vegetation, isolated many small embayments, and established a relatively stable shoreline of sand, gravel, rubble, and boulders. Fishes that require vegetated shorelines for successful spawning decreased in abundance, and those that spawned successfully on sand, gravel, rubble, and boulder shores increased. By 1973 the diversity, abundance, and distribution of YOY fish had begun to stabilize as a result of changes in the reservoir environment.

Because of the loss of river habitat and alterations caused by closure of Big Bend Dam, the abundance of species dependent on a stream or river environment declined. Several species taken as adults (National Reservoir Research Program,

<sup>2</sup>Although rainbow smelt had become common in Lake Sharpe by 1982, it is not known whether the population is self-sustaining. (R. Hanten, South Dakota Department of Game, Fish and Parks, personal communication.)

unpublished data), but that were not among the catches of YOY fish, were the pallid sturgeon (*Scaphirhynchus albus*), shovelnose sturgeon (*S. platyrhynchus*), paddlefish (*Polyodon spathula*), shortnose gar (*Lepisosteus platostomus*), and flathead catfish (*Pylodictis olivaris*). Small populations of primarily stream species, such as blue sucker, river carpsucker, sauger, *Hybognathus* sp., Topeka shiner, flathead chub, brassy minnow, creek chub, and stonecat, were being maintained in Lake Sharpe. Nelson and Walburg (1977) noted that saugers were the dominant percoid in the free-flowing Missouri River, and that as lakelike conditions developed after several years of impoundment, the populations declined to low levels in all reservoirs except Lewis and Clark Lake, which has a long stretch of natural river in the upstream portion. Periodic washout of some farm ponds, common in the Lake Sharpe drainage, may have resulted in the introduction of bluegills, largemouth bass, orangespotted sunfish, and green sunfish, which were not considered native. As a result of the rapid filling of Lake Sharpe, species requiring flooded vegetation for successful reproduction—bigmouth and smallmouth buffaloes, northern pike, and common carp—established strong year classes before the present study began but rarely thereafter (Elrod and Hassler 1969, 1971). The abundance of several species, including freshwater drum, white bass, and bigmouth and smallmouth buffaloes, increased in the later years of the study, whereas that of most other species declined. Bigmouth and smallmouth buffaloes may have responded favorably to the gradual development of aquatic vegetation in Lake Sharpe during the later years of the study. It is not known why northern pike and common carp failed to respond similarly (although the catch of common carp in trawls increased marginally in 1973–75).

During the early impoundment years, the northern pike was the most important sport species in Lake Sharpe (Hassler 1970), but as a result of poor recruitment only an occasional fish was taken by sport fishermen in the mid-1970's. Hassler (1970) noted that flooded vegetation appears to be one of the spawning requirements of this species and that reproductive success is low if such vegetation is lacking. The required vegetation was available in Lake Sharpe in only 1 year (1964), when the only large postimpoundment year class of northern pike was produced; prolonged flooding and wave action

soon destroyed the vegetation. This decline was demonstrated by gill-net catches, which declined from 8.7 per set in 1965 to 0.1 per set in 1972–75 (Elrod et al. 1987). Under existing reservoir conditions there seems to be little hope for restoration of northern pike stocks.

Abundance and variety of species were generally highest in midreservoir and in Hipple Lake. Because of apparent upstream migration of YOY fish, catches were highest in late summer (after July) in the upper reservoir, whereas they were highest in midsummer in all other areas. About 90% of all gizzard shad, white bass, yellow perch, saugers, and walleyes caught in the upper reservoir were taken after July. Absence of young fish from this area of the reservoir in early summer was probably caused by low temperature of the water discharged from Oahe Dam, situated immediately upstream, and the extreme water level fluctuations during any 24-h period caused by variable discharges. In contrast to results of similar studies of YOY fishes in upstream Lake Oahe (Beckman and Elrod 1971; June 1976), where highest catches of most species and a greater variety of species came from upper embayment stations, no significant differences were evident among catches in embayments of Lake Sharpe—probably because the embayments in Lake Sharpe are small.

There was a tendency toward stabilization of the young fish stocks in Lake Sharpe during the last 3 years of this study (1973–75). Except for walleyes, predator species such as northern pike had all but disappeared, and most forage species had declined from earlier years. The population structure seemed likely to continue to consist of one dominant predator, the walleye, supported by reduced populations of a variety of forage species.

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## Biology of the Walleye in Lake Sharpe, South Dakota, 1964-1975

by

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### Abstract

Abundance of walleyes (*Stizostedion vitreum vitreum*) in Lake Sharpe, a 22,600-ha reservoir on the Missouri River in central South Dakota, increased during the first 4 years of impoundment (1964-67) and remained relatively stable through 1975. Gill-net catches during summer were highest in the lower reservoir, but upstream migrations resulted in high abundance in the upper reservoir (tailwater of Oahe Dam) in October to May. Reproduction was successful each year; the strongest year classes developed in 1964 and 1968. Tributary embayments in midreservoir were the principal nurseries. Seine catches of young of the year provided a satisfactory index of year-class strength. Growth of young of the year averaged about 1 mm per day during summer each year. A decline in growth of adults after impoundment corresponded to an increase in abundance of walleyes and a concurrent decrease in abundance of forage fishes. Estimated mean annual mortality from ages IV to IX was 0.50 for males and 0.48 for females. Sexual maturity was generally attained 1 year earlier by males than by females, and age at sexual maturity increased by about 1 year for both sexes during the first 12 years of impoundment. Mean lengths and percentages of sexually mature walleyes were highly correlated for males 3 or 4 years old and for females 4 or 5 years old. Female walleyes predominated at all ages in the 1964-68 year classes, which were formed when the walleye population was expanding, whereas males dominated the 1969-74 year classes, which were formed under conditions of higher walleye abundance and accompanying slower growth rates. Spawning of walleyes in Lake Sharpe probably peaked during early May. If annual production of forage fishes remains adequate, the walleye population in Lake Sharpe should continue to remain near the level that existed during 1968-75. We believe that the walleye population could support a larger angler harvest than that prevailing through 1975.

The walleye (*Stizostedion vitreum vitreum*) was the most abundant and valuable game fish in Lake Sharpe, a 22,600-ha flow-through reservoir on the upper Missouri River (central South Dakota) during much of the first decade after impoundment. Catches of walleyes per standard gill-net set increased each year from 1965 to 1968 and

remained high through 1975. A concomitant decline in the population of northern pike, *Esox lucius* (Elrod and Hassler 1969), stimulated angling for walleyes; initial effort was highest in the upper reservoir, primarily in the tailwater of Oahe Reservoir. Fishing for walleyes increased greatly in the lower reservoir in 1968 and extended over much of the reservoir by 1974. Schmidt (1975) estimated that the catch during a 12-month period beginning 1 June 1973 was about 71,000 fish.

Elrod and Hassler (1969) provided estimates of relative abundance, age composition, growth and survival rates, sex ratio, and relative year-class strength of the adult walleye stock during the first

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3 years after impoundment of Lake Sharpe. Nelson and Walburg (1977) presented a general overview of the development of the walleye population in Lake Sharpe and discussed the interaction of environmental variables with time in relation to changing abundance. We present additional and supplemental data for the 12 years following impoundment (1964–75). Objectives of the work were to (1) summarize present knowledge of the biology of walleyes in Lake Sharpe, (2) report and analyze causes of population changes, and (3) suggest management measures that might increase the walleye population in this reservoir.

## Collection and Treatment of Data

Relative abundance and distribution of young-of-the-year (YOY) walleyes were estimated from catches with a bag seine (30.4 × 2.4 m; 6.4-mm bar mesh) and an 8.2-m otter trawl (19-mm bar mesh; 6.4-mm mesh cod liner), as described by Beckman (1987). Three seine hauls were made at each of

eight localities (Fig. 1) weekly in 1967–68 and biweekly in 1969–75, from late June to early September. A trawl haul was made biweekly at 12 localities during the same period. Fish in the catches were preserved in 10% formalin; in the laboratory, walleyes were counted and each fish was measured to the nearest millimeter. Further details of the sampling methods were given by Beckman (1987).

Walleyes of age I or older (herein referred to as adults, even though not all were sexually mature) were collected with a gill net (106.7 × 1.8 m) composed of seven 15.2-m panels—one each of the following meshes (centimeters, bar measure): 1.91, 2.54, 3.18, 3.81, 5.08, 6.35, and 8.89. A standard unit of fishing effort was one net set on the bottom overnight. Fishing was conducted biweekly at six reservoir locations from June through September 1965–75 and weekly or biweekly in Oahe tailwater from October through May, beginning in 1964 (Fig. 1). Sampling in Oahe tailwater during March and April was reduced after 1969 because of an increase in numbers of anglers fish-

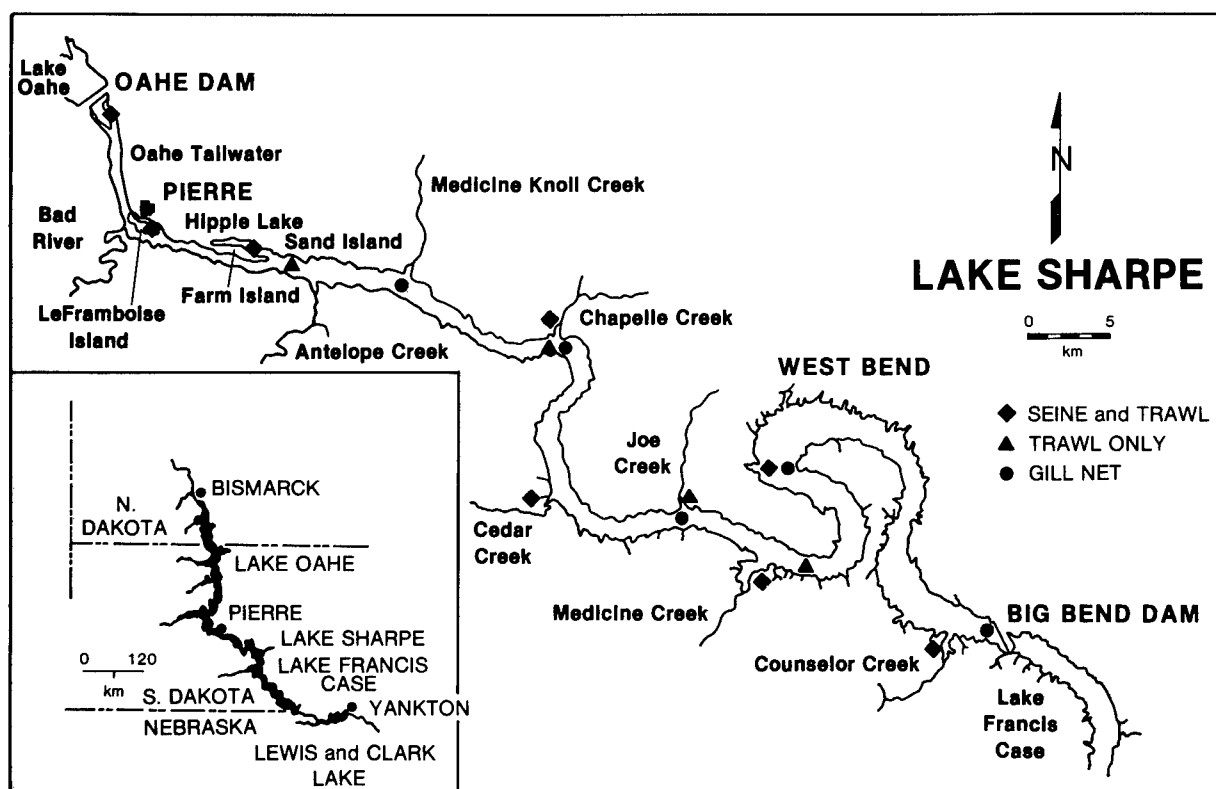


Fig. 1. Fish-sampling locations in Lake Sharpe, 1965–75.

ing there. Exploratory fishing for walleyes with gill nets, fyke nets, and trap nets in 1966 and 1969 provided additional samples.

Fork length (mm) and sex were recorded for nearly all fish taken. Fork lengths and total lengths were recorded for all walleyes collected in 1964-65 and for about 200 each year in 1966-68. The equation, total length (mm) =  $5.056 + 1.043$  fork length (mm), derived from measurements of 10 fish per 10-mm interval of fork length over the range of about 200-700 mm, was used to convert tabulated fork lengths to the total lengths used throughout this report. Gonads of virtually all walleyes were examined and classified according to five stages of development: I, immature; II, early maturing; III, mature; IV, ripe; and V, spent. The ovaries of many sexually mature females were weighed. An ovary maturity index was calculated for individual fish by the following formula (from June 1977): (ovary weight  $\times 10^3$ )/fish length<sup>3</sup>. Determination of the percentage of total fish weight contributed by the ovaries enabled us to monitor annual ovarian development and closely approximate the dates of the spawning season.

Age determinations were based on scale samples from about 97% of the more than 14,000 walleyes collected.

Relative year-class strength was estimated from the mean catch per standard unit of effort (C/f) of YOY with seines and of fish of ages II and III with gill nets during summer. Instantaneous mortality rates of YOY were estimated from linear regressions of the natural logarithm of the mean C/f on coded dates. Mortality rates of adults were calculated from the C/f by gill nets during comparable periods in successive years according to the methods of Robson and Chapman (1961).

Plots of mean lengths of YOY fish by date indicated a linear relation. Accordingly, the instantaneous growth rate and the length attained on 1 September were estimated each year from the linear regression of mean length on coded dates. Mean lengths of adults at each age were based on empirical lengths of fish collected in Oahe tailwater from October to January. Growth parameters of the von Bertalanffy growth equation were determined for adults according to Ricker (1975). Age and length at sexual maturity and percentage of sexually mature fish at different ages were derived from fish collected in Oahe tailwater during October-December.

Stomachs of 647 walleyes, ages I-VI, were removed from fish caught in gill nets during October-December 1970 and April-June 1971. Stomach contents were removed and weighed to the nearest 0.1 g. Identifiable items were counted and tabulated in terms of percent occurrence, number, and total weight.

## Abundance and Distribution

### *Young of the Year*

Catches of YOY walleyes with both the seine and trawl were lowest in 1967 and rose sharply in 1968 (Table 1). The C/f for trawling was highest in 1970, but this peak was due to a single, unusually large catch of 298 fish in Medicine Creek in July. Mean C/f's in both gears were relatively uniform after 1970. Annual seine and trawl catches (1970 values excluded) were positively correlated ( $r = 0.73$ ;  $P < 0.05$ ). Either gear was probably satisfactory for indexing the abundance of YOY walleyes; however, because of the seemingly greater consistency, we chose the seine for estimating year-class strength. Except for small catches in 1967 and large catches in 1968 and 1969, the catches (and presumably year-class strength) of YOY walleyes were relatively stable (Table 1).

Trawl catches indicated that tributary embayments were the principal nurseries of walleyes (Table 2). Nearly one-third of the catch of YOY in trawls during 1967-1975 came from Medicine

Table 1. *Average numbers of young-of-the-year walleyes caught per seine haul at 8 localities, and per trawl haul at 12 localities, in Lake Sharpe, July-September 1967-75. (From Beckman 1987.)*

Year	Gear	
	Seine	Trawl
1967	0.9	2.8
1968	7.6	11.7
1969	5.5	7.0
1970	2.9	14.2
1971	2.3	6.7
1972	3.2	7.0
1973	2.2	7.9
1974	2.5	5.8
1975	2.7	8.6

Table 2. Mean annual numbers of young-of-the-year walleyes caught per seine haul and per trawl haul at embayment, floodplain, and channel locations in Lake Sharpe, July–September 1967–75.

Location	Gear <sup>a</sup>	
	Seine	Trawl
Embayments		
Counselor Creek	3	6
Medicine Creek	9	30
Cedar Creek	4	26
Chapelle Creek	3	—
Hipple Lake	2	3
LeFramboise Island	1	5
Floodplain		
West Bend	4	6
Joe Creek	—	8
Chapelle Creek	—	8
Channel		
Medicine Creek	—	1
Chapelle Creek	—	1
Sand Island	—	1
Oahe tailwater	1	2

<sup>a</sup>Dash indicates no fishing.

Creek, about one-fourth from Cedar Creek, and about one-fourth from floodplain locations. Catches were intermediate at LeFramboise Island and in Hipple Lake and low at channel locations. Except for one catch of 67 fish in mid-September 1973, few YOY walleyes were captured in the Oahe tailwater. Mean catches of YOY walleyes with the seine were highest in the Medicine Creek embayment and lowest at LeFramboise Island and in Oahe tailwater (Table 2).

Young walleyes began dispersing from the tributary nurseries in late summer, and few could be caught in the embayments by September. Seine and trawl catches at Oahe tailwater and LeFramboise Island indicated a fall upstream migration of at least a portion of the YOY stock. Of 673 YOY walleyes caught at these two locations, 612 (91%) were taken after 1 August, and no larvae or early-stage juveniles were caught there.

The YOY fish probably moved from downstream summer nurseries in response to autumnal cooling of the shallow embayments. Warmer inflow

from Lake Oahe beginning in September (June 1987a) may have stimulated the upstream migration.

## Adults

Adult walleyes were distributed throughout Lake Sharpe, but gill-net catches in summer were higher at the three lower reservoir localities (Big Bend Dam, West Bend, and Joe Creek) than at localities farther upstream (Table 3). Mean catches increased sharply in 1967 due to recruitment of the large 1964 year class, dropped somewhat in 1969 because the 1966 and 1967 year classes were weaker, and rebounded in 1970 after recruitment of the large 1968 year class. (Year-class strength is further discussed later.) Large catches at Joe Creek and Medicine Knoll Creek in 1973 and at Joe Creek in 1974 were responsible for the high mean catches in those years. These were unusually large catches of older fish and were not indicative of a sudden rise and fall in walleye abundance, as indicated by the mean age of fish in the catches (Table 3). Mean ages also indicated that the walleye population was relatively stable during 1968–75.

Although adult walleyes were present in Oahe tailwater throughout the year, variations in their abundance there followed a seasonal pattern (Table 4). Fish were least abundant during summer; in each year, catches declined from June to August, increased in September, peaked in November, and then declined and were relatively stable during December through May. Schmidt (1975) reported that catch rates for walleyes by anglers at this locality were lowest in August, increased in September, were generally good through the winter, and peaked during May.

Mean age composition of walleyes in gill-net catches in Oahe tailwater indicated a greater influx of young fish than of older age groups during fall (Fig. 2). A high proportion of yearlings (designated as age II after 1 January) were present from October through January. By March the younger fish had left the area, and 3-year-olds predominated from April through September.

A sharp rise in mean lengths of walleyes of a given age in catches in Oahe tailwater in September and October coincided with the increased catches there, as shown for the 1964 year class in Fig. 3 (other year classes showed similar trends). Mean lengths were greatest from November to

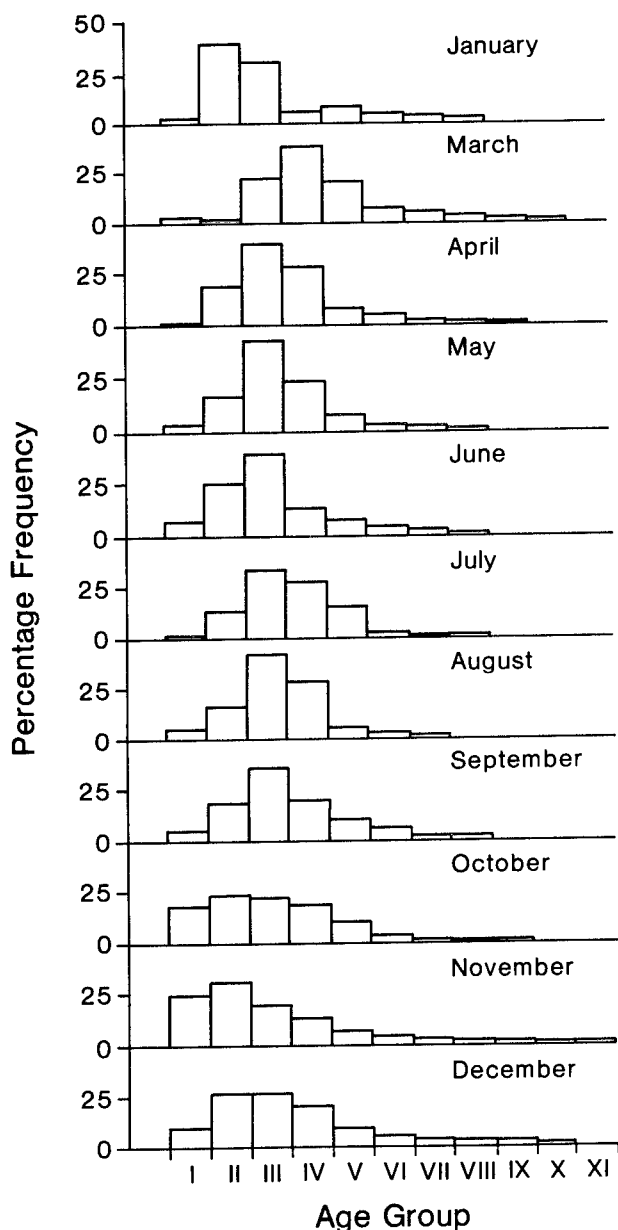


Fig. 2. Monthly mean percentage age composition of walleyes in gill-net catches at Oahe tailwater, Lake Sharpe, 1964-75.

January. The decrease in abundance after May was accompanied by a large decline in mean lengths and also by a decrease in the percentage of sexually mature fish. Length ranges suggested that walleyes from all downstream localities migrated upstream into Oahe tailwater during fall

and winter, but the length of time spent there by the fish before they moved back downstream was not determined.

## Growth and Year-Class Strength

### *Growth of Young of the Year*

Growth of YOY walleyes averaged about 1 mm per day during summer (28 June-1 September). Instantaneous growth rate varied during 1967-75, but no trends were obvious (Table 5). Growth was fastest in 1967 and slowest in 1970. Mean estimated lengths of fish of individual year classes on 1 September ranged from 90 to 104 mm. Some of the larger fish probably avoided our sampling gears or moved out of the tributary nurseries as the fish grew during summer. A few large YOY (175-251 mm long) were captured in gill nets in Oahe tailwater during fall in most years. Growth of YOY walleyes was probably underestimated, but our sampling methods and gears were consistent and differences among years were probably real. No relations were detected between growth rates of YOY walleyes and water temperature, turbidity, conductivity, water discharge rate, zooplankton abundance, or the C/f of various other YOY fishes.

### *Growth of Adults*

Mean lengths of male and female walleyes at a given age were generally greater in fall 1964 than during the same period in later years (Table 6).

Mean lengths at a given age generally declined for fish of the 1964-68 year classes and fluctuated moderately among later year classes. Mean lengths of fish that had completed 2 and 3 years of growth undoubtedly overestimated true growth rate because the faster-growing, larger individuals were more vulnerable than the smaller fish to capture with the gill nets.

Although there were annual variations in the mean empirical lengths of adults in the different localities, there was a general tendency for mean length to decrease upstream. Fish within the first three age groups in summer gill-net catches, for example, averaged about 8% longer in the lower reservoir (West Bend and Big Bend Dam) than in Oahe tailwater.

Table 3. Average number of walleyes caught per standard gill-net set in 1968-75 at five locations in Lake Sharpe, during summer, and in Oahe tailwater during spring (March-May), summer (June-September), and fall (October-January).

Location	Year												Mean
	1964 <sup>a</sup>	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	
Big Bend Dam	—	1	2	18	37	24	30	38	32	17	32	19	23
West Bend	—	3	6	8	12	14	19	14	20	28	22	15	15
Joe Creek	—	2	4	9	23	10	16	16	19	38	46	31	19
Chapelle Creek	—	4	2	5	4	7	8	14	9	14	21	19	10
Medicine Knoll Creek	—	2	5	7	7	3	14	19	17	37	20	13	13
Oahe tailwater													
Spring	—	6	6	32	37	29	20	88	57	48	4	28	32
Summer	—	8	7	22	17	8	9	15	10	9	14	4	11
Fall	26	13	36	38	42	64	67	46	39	50	60	21	42
Mean catch (summer)	—	3	4	12	17	11	16	19	18	24	26	17	
Mean age, years (summer)	—	1.8	2.1	2.8	3.3	3.4	3.2	3.4	3.6	4.0	3.9	3.9	

<sup>a</sup>Dash indicates no fishing.

The declining growth rates of walleyes in 1964-75 corresponded to an increase in abundance of adult walleyes and a concurrent decrease in abundance of forage fishes. Correlation coefficients between annual increments in lengths of walleyes in the second to fifth years of life (sexes combined) and abundance of YOY fishes of all species combined as estimated by both the seine and trawl dur-

ing 1967-75 (Beckman 1987), ranged from 0.53 to 0.68. Correlation coefficients between abundance of adult walleyes and annual length increments at these ages were negative and significant at the 0.01 level (except for fish in the second year of life). Thus, it appears that if the abundance of YOY forage fishes continues to decline, as it did during 1967-75 (Beckman 1987), and walleye abundance

Table 4. Mean number of walleyes caught per standard gill-net set in Oahe tailwater in different months, Lake Sharpe, 1964-75.

Month	Catch	Effort (no. of sets)
January	30	12
February	31	1
March	28	21
April	34	22
May	36	31
June	15	26
July	8	22
August	7	29
September	16	27
October	43	32
November	46	32
December	36	31

Table 5. Estimated instantaneous growth rates in length (28 June-1 September) and calculated mean total length on 1 September of young-of-the-year walleyes in Lake Sharpe, 1967-75.

Year	Growth rate	Mean total length (mm), 1 Sept.
1967	1.25	104
1968	1.07	101
1969	1.05	90
1970	0.90	90
1971	1.06	99
1972	1.02	93
1973	1.04	102
1974	1.11	102
1975	1.07	94

Table 6. Mean empirical total lengths (mm) and calculated grand mean weights (g) of male and female walleyes of different ages in gill-net catches in Lake Sharpe, October-January 1964-75 (numbers of fish in parentheses). Values for the strong 1964 and 1968 year classes are shown in boldface.

Sex, and collection year	Years of growth completed										
	2	3	4	5	6	7	8	9	10	11	12
<b>Males</b>											
1964	361(3)	408(12)	462(29)	491(65)	522(32)	578(4)	578(4)	—	—	—	—
1965	<b>266(13)</b>	416(5)	461(1)	494(5)	509(15)	567(3)	—	620(1)	—	—	—
1966	263(11)	<b>393(174)</b>	—	481(3)	495(6)	517(10)	554(7)	—	—	605(1)	—
1967	219(6)	372(48)	<b>423(205)</b>	—	503(2)	506(1)	568(4)	569(3)	513(1)	—	—
1968	212(4)	376(19)	424(63)	<b>457(76)</b>	499(1)	516(2)	534(1)	536(4)	—	—	—
1969	<b>243(54)</b>	317(45)	401(46)	439(53)	<b>475(43)</b>	—	—	—	—	—	—
1970	248(74)	<b>306(120)</b>	379(32)	443(33)	475(21)	<b>486(11)</b>	—	—	—	—	—
1971	230(14)	296(66)	<b>351(118)</b>	400(15)	473(14)	475(11)	<b>530(3)</b>	—	—	—	—
1972	223(10)	268(35)	352(73)	<b>379(62)</b>	437(4)	432(2)	521(1)	<b>495(1)</b>	—	—	—
1973	237(69)	291(55)	361(45)	390(61)	<b>420(32)</b>	474(1)	494(1)	504(1)	—	—	—
1974	260(130)	322(103)	371(42)	388(13)	426(12)	<b>444(12)</b>	—	509(2)	—	—	—
1975	236(17)	258(22)	352(40)	390(4)	420(1)	443(4)	—	533(2)	—	—	—
Calculated grand mean weight	176	492	862	1,182	1,591	1,835	2,533	2,515	2,131	3,755	
<b>Females</b>											
1964	338(13)	400(15)	507(27)	568(34)	611(46)	654(16)	697(6)	685(4)	—	—	—
1965	<b>243(34)</b>	—	504(1)	576(3)	612(6)	653(2)	679(3)	<b>646(1)</b>	—	—	—
1966	261(23)	<b>359(77)</b>	—	634(1)	539(2)	665(5)	679(1)	705(3)	—	—	—
1967	248(1)	344(21)	<b>472(111)</b>	514(2)	—	637(2)	627(5)	662(4)	—	646(1)	—
1968	287(1)	306(7)	418(26)	<b>529(129)</b>	519(1)	641(1)	—	618(1)	618(1)	—	—
1969	<b>247(36)</b>	314(23)	428(17)	502(100)	<b>521(89)</b>	—	—	699(1)	—	—	—
1970	249(52)	<b>311(52)</b>	375(9)	478(11)	535(24)	<b>552(28)</b>	523(1)	—	—	—	—
1971	229(20)	305(29)	<b>352(37)</b>	428(6)	538(10)	543(13)	<b>573(14)</b>	—	—	—	—
1972	207(8)	278(18)	376(22)	<b>411(11)</b>	449(6)	515(8)	586(5)	<b>680(5)</b>	—	—	—
1973	232(30)	284(37)	351(3)	416(20)	<b>431(13)</b>	480(7)	522(4)	578(7)	<b>658(7)</b>	—	—
1974	262(92)	322(24)	387(14)	401(7)	474(7)	<b>502(8)</b>	506(1)	579(1)	683(2)	<b>555(1)</b>	725(1)
1975	197(7)	260(30)	368(12)	417(6)	463(4)	460(3)	<b>529(11)</b>	533(2)	—	—	—
Calculated grand mean weight	192	411	952	1,654	1,962	2,733	3,024	3,860	4,156	3,167	5,790

does not decrease accordingly, the growth rate of adults can be expected to deteriorate further.

Geometric mean functional regressions were used to calculate the length-weight relations for walleyes caught in Oahe tailwater during October-May. Differences in the relation were evident between the sexes; the following equations were developed for each:

$$\text{Males: } \log W = -5.94 + 3.42 \log L$$

$$\text{Females: } \log W = -5.39 + 3.20 \log L$$

A comparison of grand mean weights at each age for males and females (Table 6) indicated that females averaged about 24% heavier than males of the same age group.

The von Bertalanffy growth curve equations were  $L_t = 560 [1 - e^{-0.3033(t + 0.9584)}]$  for males and  $L_t = 709 [1 - e^{-0.2827(t + 0.0357)}]$  for females. Females grew faster than males, and differences between maximum predicted lengths ( $L_\infty$ ), growth coefficients ( $K$ ), and the theoretical times at length 0 ( $t_0$ ), were all significant ( $P < 0.01$ ). Males and females both attained 93% of their maximum length after 7 years of life.

### Year-Class Strength

Catches of walleyes at ages II and III with gill nets demonstrated that the 1968 year class was the strongest and the 1964 year class the second strongest produced after impoundment of Lake Sharpe, whereas the 1966 and 1967 year classes were the weakest (Table 7). Strength of year classes produced was above average in 1971 and 1972 and below average in 1965, 1969, and 1970. Declining growth during the first few years of impoundment may have reduced the vulnerability of walleyes of ages II and III to the gill nets and caused overestimation of relative size of the earlier year classes. Mean age of fish in gill-net catches rose from 1965 to 1969, reflecting domination of the population by the strong 1964 year class (Table 3). Mean age dropped in 1970 when the

strong 1968 year class entered the catches at age II, and the succeeding predominance of this year class was reflected by a steady rise in mean age of the catches through 1973.

Catches of YOY and yearling walleyes with seines demonstrated that the 1968 year class was the largest during the 9 years in which seining was conducted (Tables 1 and 7). Correlations between mean C/f of age II and III walleyes with gill nets and C/f of YOY with seines ( $r = 0.78$ ) and yearlings with seines ( $r = 0.98$ ) were significant at the 0.05 and 0.01 levels, respectively.

Wind velocity during May, air temperature, and forage fish abundance accounted for 89% of the variation in abundance of YOY walleyes in 1967-74, and abundance of forage fish accounted for about 91% of this total (Nelson and Walburg 1977). Year-class strength of walleyes in Lake Sharpe was not significantly related to size of the spawning stock (abundance of mature females). In Oneida Lake, cannibalism on young walleyes by adults was an important factor in limiting year-class size in some years (Forney 1976). In Lake Sharpe, the relative survival from YOY to age I, as measured by seine catches, tended to be lowest when abundance of adult walleyes was highest, but the correlation coefficient ( $r = -0.31$ ) was not significant for the 1968-74 year classes.

## Mortality

### Young of the Year

Mortality rates of YOY walleyes varied from year to year but showed no trend with time (Table 8). Because of the variability of catches at given localities in different years, data from all localities were pooled in calculating the annual mean rates. The resulting estimates represented combined deaths within, and emigration from, the nurseries during about a 6-week period beginning in mid-July. Mortality was lowest in 1972 and highest in 1973.

We found no significant relation between the annual mortality estimates and any environmental or biological variable, acting singly or in combination, and concluded that the fate of each year's YOY stock was probably determined by a number of factors interacting differently in different years. The average catch of YOY walleyes per

Table 7. Mean catch of walleyes per standard gill-net set at ages II and III (June-September) and per seine haul at age I (July-September) in Lake Sharpe.

Year class	Gill net	Seine
1964	6.8	—
1965	3.7	—
1966	2.0	—
1967	1.8	—
1968	9.3	1.4
1969	3.5	0.8
1970	2.7	0.6
1971	5.0	0.8
1972	4.9	0.9
1973	—	0.2
1974	—	0.2

Table 8. *Estimated instantaneous mortality rates (15 July-1 September) of young-of-the-year walleyes, Lake Sharpe, 1967-75.*

Year	Instantaneous mortality rate
1967	0.047
1968	0.036
1969	0.025
1970	0.028
1971	0.015
1972	0.014
1973	0.065
1974	0.026
1975	0.057
Mean	0.035

seine haul was highly correlated with the catch of other YOY fishes as a group ( $r = 0.86$ ;  $P < 0.01$ ), further suggesting that general ecological conditions that governed the survival of other YOY fishes also influenced the survival of YOY walleyes.

### Adults

Peak catches of walleyes in the gill nets were generally at age III, although maximum catches for individual year classes ranged from II to IV for both sexes (Table 9). Catch curves for both males and females in the individual year classes appeared to have straight right limbs. Aberrations in the catch curves, such as the high C/f for males of the 1968 year class at age V, were usually

Table 9. *Catches of walleyes of different ages per standard gill-net set, by age, at six locations in Lake Sharpe, South Dakota, June-September 1965-75. Data for the strong 1964 and 1968 year classes are shown in boldface.<sup>a</sup>*

Sex, and year of collection	Age group										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
<b>Male</b>											
1965	<b>0.9</b>	—	T	0.1	0.1	T	—	—	—	—	—
1966	0.1	<b>1.2</b>	T	—	T	T	T	—	—	—	—
1967	T	1.0	<b>4.4</b>	T	—	T	T	T	—	—	—
1968	0.3	0.9	1.8	<b>2.1</b>	T	—	—	T	—	—	—
1969	<b>0.9</b>	0.3	0.7	0.7	<b>0.7</b>	—	—	—	T	—	—
1970	0.4	<b>3.1</b>	0.8	0.6	0.8	<b>0.4</b>	—	—	—	—	—
1971	0.4	1.2	<b>5.7</b>	0.5	0.4	0.3	<b>0.4</b>	—	—	—	—
1972	0.6	1.2	2.6	<b>3.3</b>	0.2	0.2	0.1	<b>0.1</b>	—	—	—
1973	0.5	2.2	2.0	3.1	<b>3.6</b>	0.7	0.2	0.1	<b>0.1</b>	—	—
1974	0.6	2.9	3.9	2.4	1.9	1.8	0.2	0.1	T	—	—
1975	0.3	1.7	1.7	1.8	1.0	1.0	<b>0.8</b>	0.1	T	—	—
<b>Female</b>											
1965	1.6	0.1	0.2	0.2	0.1	0.1	T	—	—	—	—
1966	0.4	<b>2.5</b>	0.1	T	T	T	0.1	T	—	—	—
1967	0.3	1.6	<b>5.4</b>	0.1	—	—	T	—	—	—	—
1968	0.4	1.2	3.0	<b>6.8</b>	0.1	—	—	T	—	—	—
1969	<b>0.8</b>	1.0	1.1	1.8	<b>2.7</b>	T	—	—	—	—	—
1970	0.5	<b>3.9</b>	1.5	1.1	1.5	<b>1.4</b>	—	—	—	T	—
1971	0.2	1.1	<b>5.9</b>	1.2	0.7	0.8	<b>0.5</b>	—	—	—	—
1972	0.3	0.8	2.2	<b>4.5</b>	0.7	0.2	0.3	<b>0.2</b>	—	—	—
1973	0.6	1.4	1.3	2.6	<b>3.4</b>	1.0	0.4	0.2	<b>0.1</b>	—	—
1974	0.6	2.1	2.5	1.5	2.2	2.8	0.5	0.1	0.1	<b>T</b>	—
1975	0.2	1.7	2.1	1.2	0.7	0.7	<b>0.7</b>	0.2	0.1	—	<b>0.1</b>

<sup>a</sup>T = trace (<0.05).

associated with a few unusually large catches, such as occurred at Joe Creek and Medicine Knoll Creek in 1973 and 1974 (Table 3).

Annual mortality estimates based on catches during June–September at ages IV–VII for the 1964–68 year classes, respectively, were 0.55, 0.53, 0.48, 0.41, and 0.50 for males and 0.63, 0.53, 0.50, 0.45, and 0.51 for females. The high mortality rate for the large 1964 year class may have resulted partly from fishing mortality, since this year class supported the bulk of the sport fishery during the early years after impoundment. However, fish were progressively smaller at the same ages in the successive year classes (Table 6), and accompanying changes in vulnerability to the gill nets may have affected the mortality estimates. The estimated annual mortality for all postimpoundment year classes combined (ages IV–IX) was 0.50 for males and 0.48 for females. Estimated annual mortality for all preimpoundment year classes combined was 0.51 for males and 0.48 for females.

We estimated the numbers of walleyes of harvestable size (age III and older) in 1973 from the estimated annual angler harvest of 71,000 fish (Schmidt 1975), annual average total mortality rate ( $A$ ) of 0.49, and assumed rates of natural mortality ( $n$ ). If  $n = 0.20$ , angling mortality ( $m$ ) was 0.36, and the number of harvestable-size walleyes in 1973 was 196,000. It is unlikely that  $n$  was less than 0.05 or greater than 0.40; these values yield estimates of 153,000 and 473,000 fish, respectively. Forney (1967) estimated that annual natural mortality of walleyes in Oneida Lake, New York, averaged about 0.05. In view of errors inherently associated with estimating angler harvest and mortality rates, we do not believe that the harvestable stock in 1973 exceeded 300,000 fish.

## Reproduction

### *Age and Size at Maturity*

Age at sexual maturity was generally 1 year less for males than for females, and increased by about 1 year for both sexes during the course of the first 12 years after impoundment (Table 10). In 1964, 82% of the males of preimpoundment year classes were mature after three growing seasons (one male matured after two growing seasons), and all were mature after 4 years. The maturity schedule of

males of the first postimpoundment year class (1964) was similar to that of preimpoundment year classes. However, the percentages of males that were mature after three growing seasons declined steadily to 3% in 1972, rose to 59% in 1974, and fell to zero in 1975. A record low of only 70% of the males were mature after four growing seasons in 1975. In 1964, 78% of the females were mature after four growing seasons, and nearly all were mature after five. During 1970–75 an average of only 5% of the female walleyes were mature after four growing seasons, and generally less than half were mature after five.

Mean lengths (Table 6) and percentages of sexually mature walleyes (Table 10) were highly correlated for males after three and four growing seasons ( $r = 0.95$  and  $0.76$ , respectively) and for females after 4 and 5 years of growth ( $r = 0.93$  and  $0.94$ ). All correlation coefficients were significant at the 0.01 level. Within individual year classes at these ages, mature fish were larger than immature fish. For example, after 4 years of growth, the mean lengths of mature females averaged 16% greater than those of immature females. An association between slower growth and increasing age at sexual maturity was also reported in Oneida Lake (Forney 1965) and Lake Erie (Wolfert 1969).

### *Sex Ratio*

Female walleyes were predominant at all ages in the 1964–68 year classes, but males dominated at most ages in the 1969–74 year classes (Table 11). The year classes that were predominantly female were formed during the early years after impoundment, when the walleye population was probably below the reservoir's carrying capacity. Numbers of mature females declined each year from 1964 to 1967, but increased markedly in 1968, when more than half the females of the abundant 1964 year class spawned for the first time (Table 10). The percentage of females changed from more than 70 for the 1967 year class to slightly over 50 for the 1968 year class (Table 11). By 1968, the walleye population was near the level that prevailed through 1975 (Table 3). Year classes produced under conditions of higher walleye abundance and the accompanying slower growth rates were dominated by males; more than 60% of the fish of the 1970 and 1971 year classes were males. Analogous

Table 10. *Percentage of sexually mature walleyes in samples collected with gill nets in Oahe tailwater, Lake Sharpe, October-December 1964-75. Data for the strong 1964 and 1968 year classes are shown in boldface (sample size in parentheses).*

Sex, and year of collection	Years of growth completed					
	2	3	4	5	6	7
<b>Males</b>						
1964	25 (4)	82 (11)	100 (26)	100 (51)	100 (24)	100 (9)
1965	<b>0 (12)</b>	100 (5)	— (0)	100 (4)	100 (9)	100 (3)
1966	0 (6)	<b>75 (119)</b>	— (0)	100 (2)	100 (4)	100 (5)
1967	0 (6)	46 (26)	<b>96 (135)</b>	— (0)	100 (2)	100 (2)
1968	0 (4)	79 (19)	100 (63)	<b>99 (76)</b>	100 (1)	100 (2)
1969	<b>0 (54)</b>	27 (45)	89 (46)	100 (51)	<b>100 (43)</b>	— (0)
1970	0 (74)	<b>26 (120)</b>	78 (32)	100 (33)	100 (21)	<b>100 (11)</b>
1971	0 (14)	11 (65)	<b>84 (111)</b>	92 (13)	100 (13)	100 (6)
1972	0 (10)	3 (35)	84 (73)	<b>97 (62)</b>	75 (4)	100 (2)
1973	0 (69)	11 (55)	87 (45)	100 (61)	<b>100 (32)</b>	100 (1)
1974	3 (130)	59 (103)	95 (41)	100 (13)	100 (12)	<b>100 (12)</b>
1975	0 (17)	0 (22)	70 (40)	100 (4)	100 (1)	100 (4)
<b>Females</b>						
1964	0 (13)	0 (14)	78 (23)	96 (26)	100 (34)	100 (15)
1965	<b>0 (30)</b>	— (0)	— (0)	100 (2)	100 (5)	100 (1)
1966	0 (19)	<b>0 (77)</b>	— (0)	100 (1)	100 (1)	100 (2)
1967	0 (1)	0 (18)	<b>59 (78)</b>	100 (2)	— (0)	100 (2)
1968	0 (1)	0 (7)	19 (26)	<b>95 (129)</b>	100 (1)	100 (1)
1969	<b>0 (36)</b>	0 (23)	18 (17)	77 (100)	<b>97 (89)</b>	— (0)
1970	0 (52)	<b>0 (52)</b>	0 (9)	82 (11)	100 (24)	<b>100 (28)</b>
1971	0 (20)	0 (29)	<b>5 (37)</b>	50 (6)	100 (10)	90 (10)
1972	0 (8)	0 (18)	9 (22)	<b>36 (11)</b>	83 (6)	100 (8)
1973	0 (30)	0 (37)	0 (3)	60 (20)	<b>77 (13)</b>	100 (7)
1974	0 (92)	0 (24)	0 (14)	43 (7)	86 (7)	<b>100 (8)</b>
1975	0 (7)	0 (29)	17 (12)	50 (6)	100 (4)	100 (3)

Table 11. *Percentage of females in samples of walleyes collected with gill nets at six locations in Lake Sharpe, June-September 1965-75. Sample size is shown in parentheses.*

Year class	Age group							
	I	II	III	IV	V	VI	VII	≥ VIII
1964	63 (106)	67 (232)	55 (343)	77 (428)	80 (164)	78 (83)	56 (39)	69 (29)
1965	73 (30)	62 (89)	63 (230)	72 (123)	66 (109)	74 (53)	72 (18)	76 (17)
1966	91 (11)	57 (105)	61 (90)	63 (83)	65 (52)	50 (24)	61 (31)	62 (16)
1967	60 (35)	78 (65)	66 (107)	73 (81)	74 (47)	59 (80)	68 (34)	73 (11)
1968	47 (79)	56 (336)	51 (558)	58 (375)	49 (338)	61 (218)	46 (69)	—
1969	53 (45)	47 (110)	45 (229)	46 (283)	53 (199)	41 (79)	—	—
1970	34 (32)	39 (98)	40 (160)	38 (183)	43 (81)	—	—	—
1971	36 (45)	38 (175)	39 (308)	39 (147)	—	—	—	—
1972	54 (56)	42 (237)	43 (231)	—	—	—	—	—
1973	47 (57)	50 (165)	—	—	—	—	—	—
1974	41 (22)	—	—	—	—	—	—	—

shifts in sex ratio have been reported for other species: Smith (1971) reported a shift from male dominance at high population levels to female predominance at low population levels for sea lampreys (*Petromyzon marinus*) in the Great Lakes; and Brown (1970) showed that a sharp decline in the population of bloaters (*Coregonus hoyi*) in Lake Michigan was accompanied by a shift to extreme female predominance.

The sex ratio in a sample of fish is frequently a function of gear selectivity or seasonal availability. Casselman (1975) reported that, in northern pike, males were predominant in samples taken during spring at spawning time and in fall when reproductive products were accumulating, but that females were predominant in samples collected during summer and winter. He believed that female northern pike required more food, and that their more extensive foraging activity during summer and winter increased their susceptibility to capture. In Lake Sharpe, walleyes that migrated into Oahe tailwater in fall were predominantly males at younger ages, whereas females predominated among older fish. For the 1964 year class, male walleyes were predominant at ages II and III, and females at age IV and older (Fig. 3). Among later year classes, males were predominant through age VI. Inasmuch as the method, times, and places of sampling remained unchanged during the June-September surveys, the change in sex ratios probably reflected a real change in the walleye population.

### Sexual Maturation and Spawning

The maturation and spawning cycle of walleyes was determined from ovary indices (ratios of ovary weight to fish length) of 324 females collected mostly in Oahe tailwater during 1964-65. The semi-weekly mean ovary indices were at an annual low from June to mid-July (Fig. 4), jumped sharply higher in October, and increased irregularly thereafter until April. Because the mean index dropped abruptly during the first 2 weeks in May, we concluded that spawning of walleyes in Lake Sharpe peaked during early May.

Examination of walleye gonads collected in Oahe tailwater indicated that spawning did not occur at that locality. No ripe females were caught there, and the proportion of mature fish in the catches decreased rapidly beginning in early April each year. The capture of large numbers of ripe and partly spent females in trap nets in the Medicine and Cedar creek embayments in early May 1969 suggested that these areas were important spawning grounds, and large catches of YOY walleyes with seines and trawls at these localities in most years tended to support this suggestion.

### Food

Only 29% of the walleye stomachs collected during fall 1970 and spring 1971 contained food. Fish

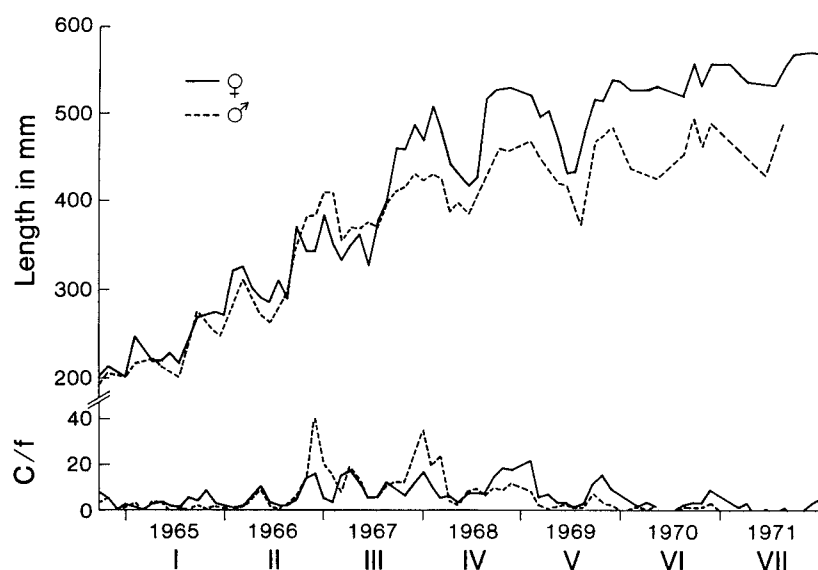


Fig. 3. Mean total length and catch per gill-net set (C/f) of walleyes of the 1964 year class at ages I to VII at Oahe tailwater, Lake Sharpe, October 1964 to January 1972 (no data plotted for February).

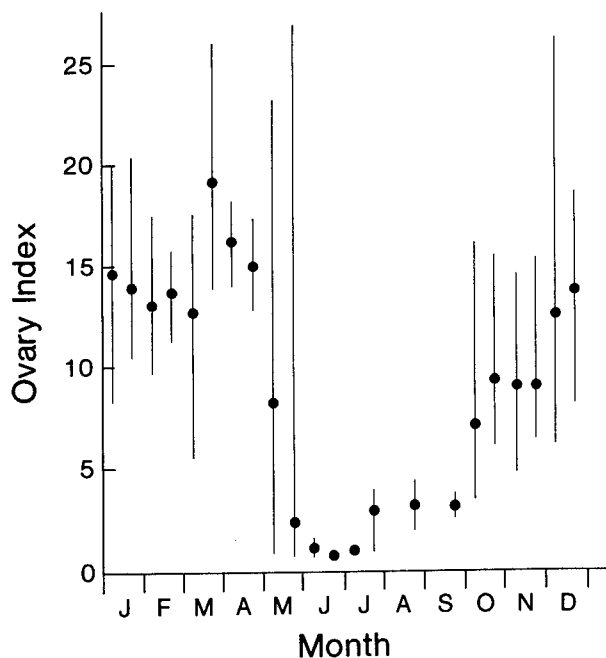


Fig. 4. Seasonal maturation cycle of walleyes, based on the range (vertical lines) and mean (dots) of ovary indices (ratios of ovary weight to fish length) of 324 females from Lake Sharpe, 1964-65.

remains were present in 97% of the stomachs with food and made up nearly 100% of the total weight of food. Gizzard shad (*Dorosoma cepedianum*) was the principal fish species eaten (Table 12), followed by yellow perch (*Perca flavescens*) and white bass (*Morone chrysops*). Most of the stomachs were collected in Oahe tailwater, and the high incidence of empty stomachs indicated either that walleyes migrating into Oahe tailwater were not feeding actively, or that the abundance of forage fishes in relation to that of walleyes was low. Considering the large numbers of walleyes in the area, the relative scarcity of forage fishes is the more plausible explanation. The relative frequency of gizzard shad in walleye stomachs was high in fall and low in spring (Table 12), reflecting the migration of YOY gizzard shad into Oahe tailwater in fall and the die-off of YOY gizzard shad during winter (June 1987b). Most of the stomachs in spring samples that contained food (largely unidentifiable fish remains) were collected at lower reservoir locations during June.

### Interaction of Walleyes with Other Predatory Fishes

Species composition of fishes in Lake Sharpe changed markedly during 1964-75 as a result of ecological changes that accompanied or followed impoundment. Inundation of terrestrial vegetation favored highly successful reproduction of several species, including northern pike, in the initial year (1964). Consequently the northern pike was the predominant predator during 1965; C/f in gill nets was nearly 3 times that of walleyes and almost 6 times that of saugers, *Stizostedion canadense* (Table 13). However, the elimination of many small embayments and deterioration of habitat in others due to erosion, sedimentation, and destruction of submerged vegetation resulted in greatly reduced reproduction of northern pike after 1964. Abundance of northern pike declined each year from 1965 to 1970 and remained very low through 1975. If northern pike were competing with walleyes for food, the competition was short-lived and apparently had little effect on the walleye stock.

In the Missouri River reservoirs, both walleyes and saugers spawn over boulder and rubble substrate, but walleyes generally spawn along the reservoir shorelines, whereas saugers spawn in the

Table 12. Frequency of occurrence of food items in stomachs of walleyes that contained food, during fall (October-December) 1970 and spring (April-June) 1971, Lake Sharpe.

Food	Season and (in parentheses) number of stomachs with food <sup>a</sup>	
	Fall (158)	Spring (30)
Zooplankton	0	5
Insects	1	1
Fish		
Gizzard shad	127	1
White bass	14	0
Yellow perch	15	0
Emerald shiner <sup>b</sup>	0	4
Walleye	3	0
Pimephales sp.	0	1
Unidentified cyprinids	0	2
Unidentifiable remains	1	16

<sup>a</sup>Empty stomachs not represented here: 313 in fall and 146 in spring.

<sup>b</sup>*Notropis atherinoides*.

Table 13. Mean catches of major predator fishes per standard gill-net set at six locations in Lake Sharpe, June–September 1965–75.

Year	Species		
	Walleye	Northern pike	Sauger
1965	3.5	8.7	1.4
1966	4.6	4.6	1.4
1967	12.9	2.4	2.5
1968	16.8	1.1	3.0
1969	11.0	0.6	2.5
1970	16.2	0.2	2.8
1971	19.3	0.2	2.0
1972	17.8	0.1	1.4
1973	23.4	0.1	0.8
1974	26.2	0.1	1.6
1975	17.0	0.1	1.4

more riverlike upper sections of the reservoirs (Nelson and Walburg 1977). Saugers reproduced successfully in Lake Sharpe each year after impoundment, but year classes were small in relation to those of walleyes. Gill-net catches of walleyes averaged about 10 times those of saugers during 1968–75 (Table 13). Saugers were found primarily in the upper portion of Lake Sharpe where conditions were more riverine, and the relatively small amount of this riverine habitat available has probably been a much more important factor than competition with walleyes in limiting the sauger population.

Abundance of other predatory fishes, such as white bass, shortnose gar (*Lepisosteus platostomus*), and burbot (*Lota lota*), was very low in Lake Sharpe. These species evidently had little effect on walleyes, either through competition for food or predation on young walleyes.

## Discussion

Stocks of forage fish were apparently adequate to maintain the walleye population in a healthy condition throughout the first 12 years of impoundment. Growth of adult walleyes was

associated with abundance of forage fishes, but was relatively stable during 1970–75. Walleyes are opportunistic predators, and their diet generally reflects the abundance and availability of prey fishes of a suitable size (Parsons 1971; Wagner 1972; Swenson 1977); when abundance of other forage species is low, walleyes may become extremely cannibalistic (Chevalier 1973; Forney 1976). However, cannibalism did not appear to be a significant problem in Lake Sharpe. If annual production of forage fishes remains adequate, the walleye population there should continue to remain near the level that prevailed during 1968–75.

Inasmuch as YOY gizzard shad were clearly an important food of walleyes, a major reduction in their abundance could adversely affect the walleye stock. Lake Sharpe is the upstream limit of the distribution of gizzard shad in the Missouri River, and YOY experienced virtually total overwinter mortality every year during 1964–75, except in 1966–67 (June 1987b). The gizzard shad population could become greatly reduced or even extinct in the reservoir. If forage fish stocks become seriously decreased due to a severe reduction or disappearance of gizzard shad, the stocking of adult gizzard shad in Hipple Lake—the most productive spawning and nursery area for the species (June 1987b)—would be strongly recommended.

Rainbow smelt (*Osmerus mordax*), which were introduced into Lake Sakakawea, a main-stem Missouri River reservoir in North Dakota in 1971 (Berard 1978), were not strongly established in Lake Sharpe by 1975 (Beckman 1987). Nevertheless, considerable numbers occasionally passed through the turbines of Oahe Dam (J. Riis, South Dakota Department of Game, Fish and Parks, personal communication). Thus they may periodically supplement the forage available to walleyes.

Regular observations of the walleyes and forage-fish stocks should be made to detect signs of instability and impending problems. For example, a shortage of forage fishes would be evident from low catches during a trawling or seining survey and also from further declines in growth rates of adult walleyes. The occasional occurrence of weak year classes of walleyes probably would not seriously affect the fishery, but regular incidence of smaller than average year classes would be cause for concern.

The walleye population in Lake Sharpe was apparently not threatened by overexploitation

during the first 12 years of impoundment. The annual harvest of 71,000 walleyes (3.14/ha) weighing 35,500 kg (1.57 kg/ha) estimated by Schmidt (1975) would have been in the lower third of yield values published by Carlander (1977). The average walleye in the creel (500 g) would have been about 336 mm long, which was equivalent to a fish that had completed 3 to 4 years of growth. We believe that the walleye population could probably support a greater angler harvest than that prevailing in 1975.

## Acknowledgments

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## Biology of the Yellow Perch in Lake Sharpe, South Dakota, 1964-1975

by

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### Abstract

The yellow perch (*Perca flavescens*) was studied during the first 12 years after impoundment of Lake Sharpe (1964-75), a 22,600-ha flow-through reservoir on the main-stem Missouri River in South Dakota. Yellow perch ranked second in abundance (after gizzard shad, *Dorosoma cepedianum*) in seine and trawl catches of young of the year fishes and fifth in abundance in gill-net catches of adults. Abundance of both young and adult yellow perch decreased markedly (ca. 80%) during the study period. We attributed the decline to a reduction in the brood stock and a general degradation, by sedimentation and erosion, of spawning and nursery grounds in tributary embayments. Growth of young of the year increased during 1967-75 and was inversely related to abundance. Mortality estimates for the young varied little from year to year. Growth of adults was variable, and no trend over time was detected. Fish of ages II and III dominated the gill-net catches; the oldest caught were age VII. The average annual survival rate of adults was lower for males (12%) than for females (20%). Most males were sexually mature at age I and females at age II. Spawning occurred from mid-April to mid-May at water temperatures of 8.9 to 11.8°C. Because of the importance of young-of-the-year yellow perch as forage fish in Lake Sharpe, provision of spawning substrate in tributary embayments is suggested as a possible method of enhancing reproduction.

Young yellow perch (*Perca flavescens*) are important in the diet of predatory fishes in Lake Sharpe, South Dakota (Elrod et al. 1987; National Reservoir Research Program [NRRP], unpublished data). This study of the yellow perch population was part of an investigation of fish stocks conducted during the first 12 years after the 1963 impoundment of 22,600-ha Lake Sharpe, the last of six main-stem reservoirs to be completed on the upper Missouri River. Objectives of the study were to (1) obtain information on the biology of the yellow perch, (2) evaluate population changes

in the species, and (3) develop management recommendations to increase its abundance. We consider here the distribution, abundance, year-class strength, growth, survival, and other aspects of the biology of the yellow perch in relation to environmental changes resulting from filling of the reservoir and the subsequent water-management regimen. The physical, chemical, and biological characteristics of Lake Sharpe were described by June (1987).

### Collection and Treatment of Data

Young-of-the-year (YOY) yellow perch were collected during annual assessments of the stocks of young fish and minnows in Lake Sharpe dur-

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ing 1967–75, as described by Beckman (1987). The young fish were sampled with a bag seine (30.5 × 2.4 m; 6.4-mm mesh, bar measure) and an otter trawl (8.2 m; 19-mm mesh body and 6.4-mm mesh cod liner). Three standardized seine hauls were made at eight sampling localities (Fig. 1) from late June to early September. Frequency of sampling was weekly during 1967 and 1968 and biweekly thereafter. A standardized trawl haul was also made biweekly at 12 localities (Fig. 1) during the same period. The mean catch per standardized seine or trawl haul (C/f) was used to estimate the relative abundance and distribution of YOY fish.

Three seining localities (Oahe tailwater, LeFramboise Island, and Hipple Lake) were classified as “upper reservoir,” three (Chapelle, Cedar, and Medicine creeks) as “midreservoir,” and two (West Bend and Counselor Creek) as “lower reservoir.” Four trawling localities were classified as “channel” (Oahe tailwater, Sand Island, Chapelle Creek channel, and Medicine Creek channel), three as “floodplain” (Chapelle and Joe creeks and West Bend), and five as “embayment” (LeFramboise

Island, Hipple Lake, and Cedar, Medicine, and Counselor creeks).

All YOY yellow perch in the catches were preserved in 10% formalin and returned to the laboratory to be counted and measured. Fork lengths (FL) of randomly chosen specimens (as many as 50, when available) from each seine or trawl haul were measured to the nearest millimeter.

Yellow perch of age I and older (here termed “adults”) were sampled during 1964–75 with a graded-mesh bottom gill net (106.7 × 1.8 m) composed of a 15.2-m panel of each of the following mesh sizes (centimeters, bar measure): 1.91, 2.54, 3.18, 3.81, 5.08, 6.35, and 8.89. A unit of effort was one gill net fished overnight. Sampling was conducted biweekly from June to September at six reservoir locations (Fig. 1), and (except as noted below) weekly from October to May at one of them, Oahe tailwater. The frequency of sampling at Oahe tailwater during March and April was reduced to biweekly after 1969 to reduce interference with the heavy early-season sport fishery. A

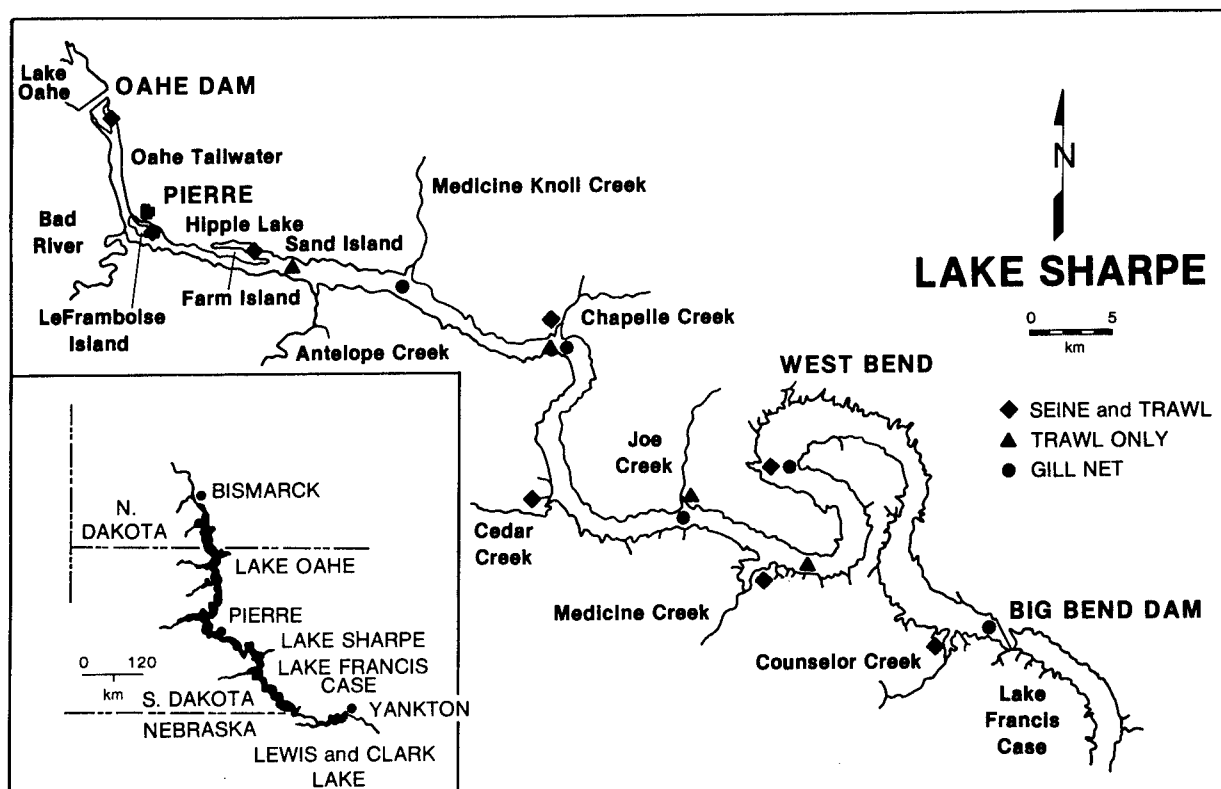


Fig. 1. Fish-sampling locations in Lake Sharpe, 1964–75.

collection year extended from 1 March to 31 January of the following year.

Fork length (mm) and sex of most adult fish were recorded. Both total and fork lengths were measured for 10 fish from each 10-mm (fork) length group over the range of about 80 to 200 mm, and fork lengths were converted to total lengths (used throughout this report) by the following equation: total length =  $1.21 + 1.03$  fork length.

Stage of sexual maturity was determined by examination of gonads. The ovaries of most females were removed, weighed, and classified according to the stages of development given by June (1977). The onset and progress of ovarian development and the mean date of annual spawning were determined from ovary indices calculated for fish by the following formula (from June 1977): (ovary weight  $\times 10^4$ )/fish length<sup>3</sup>.

Scales were taken from the left side below the lateral line and the origin of the dorsal spines. Annual growth was determined by measuring projected scale images and back-calculating fish lengths. A linear relation between the anterior scale radius and fork length was assumed and best described by the following equation: fork length (mm) =  $33.8 + 1.00$  anterior scale radius (mm  $\times 42$ ). (Fork lengths were converted to total lengths for use here.)

Estimates of relative abundance and year-class strength were based on the mean catch per gill-net set (C/f). Catch curves were constructed from the mean C/f of fish at each age at the six sampling locations during the June–September period and survival rates were calculated (Robson and Chapman 1961).

## Characteristics of Young of the Year

### *Distribution and Abundance*

Yellow perch were the second most abundant YOY fish in seine and trawl catches in Lake Sharpe during 1967–75, being outranked only by gizzard shad (*Dorosoma cepedianum*). Yellow perch accounted for nearly one-fourth of the total combined seine and trawl catches during the 9-year period; they dominated the seine catch in 1967 and the trawl catches in 1967 and 1968 (Beckman 1987).

Seine catches during 1967–75 indicated that YOY yellow perch were nearly always most abundant in the middle and lower reservoir (Table 1). Combined catches in these areas averaged 86% of the total. During 1967–68, about 80% of the catch came from the lower reservoir and about 13% from the middle; in 1969, catches in the middle and lower reservoir were about equal and together accounted for 99% of the total. Thereafter, combined catches in the two areas ranged from 63 to 91% of the total. No larval yellow perch were taken at the upper two sampling localities in any year, but juveniles appeared in the catches beginning in middle or late summer.

Of the total trawl catch of YOY yellow perch during 1967–75, 69% were taken in tributary embayments (Table 1). Increased numbers were taken in the floodplain in the early 1970's, and catches in the floodplain and in the embayments were similar by 1975. Few fish were taken in the channel areas in any year.

Table 1. Mean percentages of young-of-the-year yellow perch caught by seine and trawl in major areas of Lake Sharpe, 1967–75 (percentages determined from catch per unit effort within area).

Gear and area	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
Seine										
Upper reservoir	7	7	1	15	11	9	37	18	16	13
Middle reservoir	15	11	49	56	41	27	44	68	53	40
Lower reservoir	78	82	50	29	48	64	19	14	30	46
Trawl										
Embayment	68	94	58	89	68	83	53	66	45	69
Flood plain	30	6	33	10	31	16	40	32	48	27
Channel	2	1	8	1	1	1	6	2	6	3

Overall abundance and distribution of YOY yellow perch, as shown by both seine and trawl catches, were extremely variable during 1967-75 (Table 2). Mean annual seine and trawl catches were highly correlated ( $r = 0.84$ ;  $P < 0.01$ ). Mean C/f for both seine and trawl was highest in 1968; most fish were caught in the lower reservoir. Abundance of young decreased in 1969, and by 1971 it was only 6% of that in 1968. Seine catches increased in 1972 and fluctuated around this new higher level through 1975. Trawl catches from 1972 to 1975 were more variable. Seine and trawl

catches of other YOY fishes showed similar trends (Beckman 1987).

Water temperature, discharge rate, zooplankton abundance, and abundance of YOY and adults of other fish species were not significantly correlated with abundance of YOY yellow perch.

### Growth

Lengths of YOY yellow perch in the seine samples ranged from 14 to 90 mm and those in trawl samples from 16 to 87 mm. Length-frequency dis-

Table 2. Mean numbers of young-of-the-year yellow perch caught per haul of a seine or trawl in various localities of Lake Sharpe, 1967-75. See Beckman (1987) for details of sampling program.

Gear and locality <sup>a</sup>	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
<b>Seine</b>										
Embayment										
Counselor Creek	241	176	214	17	13	62	16	9	15	85
Medicine Creek	54	122	333	44	16	48	52	164	48	98
Cedar Creek	23	29	24	14	9	8	16	12	41	20
Hipple Lake	35	70	1	18	5	10	10	12	13	19
LeFramboise Island	2	33	3	7	3	6	33	20	9	13
Floodplain										
West Bend	87	729	34	17	14	26	6	17	28	106
Chapelle Creek	23	35	4	41	9	2	8	11	27	18
Channel										
Oahe tailwater	8	13	<1	1	<1	2	20	17	14	8
Mean	59	151	77	20	9	20	20	33	24	46
<b>Trawl</b>										
Embayment										
Counselor Creek	704	1,707 <sup>b</sup>	8	34	23	11	36	4	1	281
Medicine Creek	21	26	19	48	29	21	58	45	18	32
Cedar Creek	28	20	6	41	19	7	32	33	10	22
Hipple Lake	8	7	2	49	2	37	25	38	11	20
LeFramboise Island	17	1	0	40	6	<1	136	14	28	27
Floodplain										
West Bend	98	42	6	4	8	5	38	24	18	27
Joe Creek	8	4	2	2	7	1	62	9	12	12
Chapelle Creek	45	23	4	8	7	3	32	22	14	18
Channel										
Medicine Creek	1	<1	0	0	0	0	7	0	0	1
Chapelle Creek	0	2	1	0	<1	0	1	1	2	1
Sand Island	6	2	1	2	<1	<1	5	1	<1	2
Oahe tailwater	12	1	0	<1	0	0	15	1	6	4
Mean	79	153	4	19	8	7	37	16	10	37

<sup>a</sup>See Fig. 1 for locations.

<sup>b</sup>The total for Counselor Creek in 1968 was strongly influenced by a catch of 6,899 young-of-the-year yellow perch in one trawl haul.

tributions of fish in the three seine samples collected within a given locality on a given date usually contained fish of the same length range, and differences between the sample means seldom showed heterogeneity. Therefore, the three samples taken on a given date were combined, and a single mean length for a locality was calculated.

Plots of the mean length of YOY yellow perch by date for each sampling locality showed that growth during the first summer of life was linear, but that lengths of fish in different localities differed. Accordingly, linear regressions of mean length on coded date (25 June = 1, 26 June = 2, etc.) were calculated, and the instantaneous summer growth rate and mean length on 23 August were estimated from seine catches at each sampling locality.

Growth rates of YOY yellow perch in Lake Sharpe varied with locality and year of collection. A two-way analysis of variance of the data in Table 3 indicated highly significant differences in growth rates among localities ( $F_{5,40} = 12.07$ ;  $P < 0.01$ ) and among years  $F_{8,40} = 5.72$ ;  $P < 0.01$ ). Chapelle Creek and Oahe tailwater were excluded from the analysis because the data were insufficient. Growth was generally faster in the lower reservoir than in the middle or upper reservoir, and was slowest in Hipple Lake. The increased growth in a downstream direction was opposite the trend shown for YOY of this species in Lake Oahe (June 1976); however, the grand mean rates in Lake Sharpe (0.51) and Lake Oahe (0.53) were similar. The relatively high growth rates in the upper two localities in Lake Sharpe (Oahe tailwater and LeFramboise Island) were associated

with apparent migrants (consisting of the largest YOY) that first entered the seine catches during middle or late summer each year.

Mean annual growth rate for all localities combined was notably slower during 1967-71 (0.46) than during 1972-75 (0.56). A similar trend was demonstrated by the calculated mean lengths on 23 August for each year (Table 4) and, despite some variability, this trend was evident in every locality. The calculated annual mean lengths on 23 August in Lake Sharpe and the calculated lengths on this date for Lake Oahe given by June (1976) for the years 1967-74 showed the same general trend (Fig. 2); both trend lines were significant at the 1% level.

Efforts to identify specific factors that may have influenced the growth of young yellow perch gave no clear indication of any one dominating factor. However, the calculated mean length on 23 August and abundance in seine catches were inversely related ( $r = -0.64$ ;  $P < 0.10$ ). A similar relation was shown for this species in Lake Oahe by June (1976); however, growth of young yellow perch was not related to their abundance in the Red Lakes, Minnesota (Ney and Smith 1975), nor in Oneida Lake, New York (Noble 1975).

Other variables examined in relation to YOY yellow perch growth in Lake Sharpe were seasonal water temperature, water-discharge rate, abundance of other YOY and adult fishes, and zooplankton abundance. Of these, growth was most highly and inversely correlated with the abundance of YOY gizzard shad ( $r = -0.69$ ;  $P < 0.05$ ); and a positive relation was indicated

Table 3. *Calculated mean instantaneous summer growth rates in total length of young-of-the-year yellow perch caught by seine in various sampling localities of Lake Sharpe, 1967-75.*

Locality	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
Counselor Creek	0.46	0.50	0.52	0.54	0.61	0.61	0.66	0.52	0.74	0.57
West Bend	0.46	0.45	0.52	0.44	0.63	0.67	0.54	0.67	0.63	0.56
Medicine Creek	0.44	0.50	0.56	0.52	0.52	0.60	0.56	0.52	0.54	0.53
Cedar Creek	0.39	0.41	0.53	0.45	0.43	0.44	0.61	0.74	0.52	0.50
Chapelle Creek	0.45	0.45	a	0.31	0.38	0.31	0.67	0.63	0.46	0.46
Hipple Lake	0.32	0.32	0.38	0.24	0.36	0.48	0.36	0.42	0.40	0.36
LeFramboise Island	0.34	0.51	0.57	0.48	0.44	0.60	0.52	0.51	0.64	0.51
Oahe tailwater	0.64	0.43	a	a	a	a	0.59	0.68	0.72	0.61
Mean	0.44	0.45	0.51	0.43	0.48	0.53	0.56	0.59	0.58	0.51

<sup>a</sup>Insufficient data.

Table 4. Calculated mean total lengths (mm) on 23 August of young-of-the-year yellow perch caught by seine in various sampling localities of Lake Sharpe, 1967-75.

Locality	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
Counselor Creek	66	67	64	72	74	76	79	75	81	73
West Bend	66	66	65	67	72	78	76	80	75	72
Medicine Creek	65	66	66	70	68	73	74	74	69	69
Cedar Creek	56	59	62	69	64	64	75	79	65	66
Chapelle Creek	51	54	a	60	61	55	77	72	61	61
Hipple Lake	49	52	59	56	60	64	68	71	66	60
LeFramboise Island	51	56	53	63	60	62	69	68	66	61
Oahe tailwater	56	52	a	a	a	a	68	69	70	63
Mean	58	59	62	65	66	67	73	74	69	66

<sup>a</sup>Insufficient data.

between growth and the abundance of the cladoceran *Daphnia* ( $r = 0.68$ ;  $P < 0.05$ ). (*Daphnia* was the principal food item in stomachs of 531 YOY yellow perch, 16-63 mm long, taken from upstream Lake Oahe during 1966-68 [NRRP, unpublished data].) The increased growth of YOY yellow perch in Lake Sharpe during 1967-75 may be attributable to their reduced abundance, but food supply and the decreased abundance of YOY gizzard shad were also probably important.

### Mortality

Apparent mortality rates of YOY yellow perch during the first summer of life were estimated

from linear regressions of the natural logarithm of the mean C/f by seines on coded dates from 1 July to 15 September. Because no heterogeneity in the mortality estimates among sampling localities was indicated, data from all localities were combined.

Except for 1969, the estimated overall daily mortality rates were similar in different years (Table 5). Full recruitment of YOY yellow perch to the seine did not occur in 1969 until the last week in July, fully 3 weeks later than in other years; thus the mortality rate was probably biased upward.

Estimated daily mean instantaneous mortality rates of YOY yellow perch in Lake Sharpe were generally lower than those in Lake Oahe (June

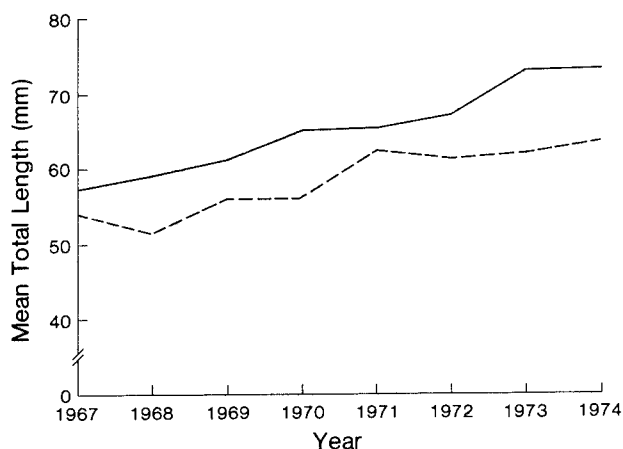


Fig. 2. Calculated mean total lengths of young-of-the-year yellow perch in Lake Sharpe (solid line) and Lake Oahe (broken line), 1967-74.

Table 5. Estimated daily instantaneous mortality rates of young-of-the-year yellow perch, based on the mean catch per seine haul during the period 1 July-15 September, in all localities of Lake Sharpe, 1967-75.

Year	Mortality rate
1967	0.056
1968	0.044
1969	0.147
1970	0.046
1971	0.050
1972	0.056
1973	0.048
1974	0.046
1975	0.063
Mean	0.062

1976). The grand mean mortality rates for the 8-year period 1967-74 were 0.062 in Lake Sharpe and 0.075 in Lake Oahe.

## Characteristics of Adults

### *Distribution and Abundance*

The yellow perch was the fifth most abundant species in the gill-net catches at six locations in Lake Sharpe during 1964-75. It was outranked by the walleye (*Stizostedion vitreum vitreum*), common carp (*Cyprinus carpio*), shovelnose sturgeon (*Scaphirhynchus platyrhynchus*), and channel catfish (*Ictalurus punctatus*) and, in turn, outranked 31 other species captured with gill nets during the 12-year period (NRRP, unpublished data).

During summer, adults were generally most abundant in the lower reservoir and least abundant in the upper reservoir (Table 6). The 11-year mean C/f at Big Bend Dam, for example, was nearly twice that in any other locality. Catches decreased progressively upstream and were lowest at Medicine Knoll Creek, where a total of only five adults were taken during 1965-75. Mean abundance of adults in Oahe tailwater appeared high when compared with that in some downstream localities (Table 6); the summer mean C/f (5.0) was heavily weighted by the high catches in 1967 and reflected the impact of the large 1964

year class. Summer catches in 1968 continued to be influenced by this abundant year class, but in the following year the C/f dropped markedly and remained relatively low thereafter. Mean gill-net catches of yellow perch in Oahe tailwater were lowest during spring (March-May) and highest during summer (June-September), although after 1968 the catches were usually highest during fall (October-January).

The summer mean C/f of adult yellow perch rose to a peak in 1967, declined to a low in 1972, and increased slightly thereafter (Table 6). Essentially, the population increased during the first 3 years after impoundment of Lake Sharpe and then stabilized at a much lower level. This same pattern was shown for yellow perch after the impoundment of Lake Oahe (Nelson and Walburg 1977).

### *Age Composition and Year-Class Strength*

Of 1,474 adult yellow perch classified by age, fish of ages II and III accounted for 48% and 32% of the total, respectively; ages I and IV contributed most of the remainder (Table 7). Yearlings dominated the catches in 1965 and 1973, but were relatively scarce in other years and were lacking in 1969 (Fig. 3). Fish of age II dominated the catches in all but 2 of the remaining years (1967 and 1969), when fish of age III were most common.

In studies of other Missouri River reservoirs, Gasaway (1970) found no yellow perch older than

Table 6. Catches of adult yellow perch per gill-net set in five localities (summer) of Lake Sharpe and in Oahe tailwaters (spring, summer, and fall), 1964-75.

Locality	1964 <sup>a</sup>	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
Big Bend Dam	—	6.8	1.7	12.0	37.8	6.4	5.9	9.8	3.0	3.8	9.2	5.9	9.3
West Bend	—	4.0	10.7	19.0	10.2	2.9	1.4	0.5	0.9	1.3	1.5	2.8	5.0
Joe Creek	—	0.4	0.5	2.8	1.0	0.5	0.8	0.4	0.6	5.5	4.5	1.2	1.7
Chapelle Creek	—	0.3	0.3	0.6	0	0.2	0.2	0.1	0	0.9	0.2	0.1	0.3
Medicine Knoll Creek	—	0	0.4	0	0	0	0	0	0	0.1	0	0	<0.1
Oahe tailwater													
Spring	—	0.8	0.9	1.4	1.0	0	0	0	0	0.3	0	1.5	0.5
Summer	—	1.0	4.7	37.5	7.9	0.8	0.5	0.4	1.1	0.6	0.1	0.5	5.0
Fall	12.3	0.2	2.7	3.8	0.8	2.0	0.7	1.6	1.1	0.6	0.8	0.5	2.5
Mean (summer)	—	2.1	3.0	12.0	9.5	1.8	1.5	1.9	0.9	2.0	2.6	1.6	3.5

<sup>a</sup>Dashes indicate no fishing.

Table 7. Number of male (M) and female (F) yellow perch of different ages in gill-net catches in June-September, Lake Sharpe, 1965-1975.

Year of collection	Age group and sex														Total		Sex ratio (F/M)
	I		II		III		IV		V		VI		VII				
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
1965	12	31	2	5	4	1	—	—	—	—	—	—	—	—	18	37	2.1
1966	4	6	43	70	—	3	—	3	—	—	—	—	—	—	47	82	1.7
1967	5	19	64	62	74	172	—	3	—	—	—	—	—	—	143	256	1.8
1968	1	—	34	147	9	51	7	43	1	—	—	—	—	—	52	241	4.6
1969	—	—	2	25	5	49	—	5	—	3	—	—	—	—	7	82	11.7
1970	—	2	1	32	1	19	1	13	—	—	—	—	—	—	3	66	22.0
1971	—	7	4	33	2	19	1	12	2	6	—	1	—	—	9	78	8.7
1972	1	6	3	21	—	8	—	3	—	2	—	—	—	—	4	40	10.0
1973	2	43	4	25	1	12	—	6	—	2	1	1	—	1	8	90	11.2
1974	1	15	16	67	2	17	—	5	—	3	—	—	—	—	19	107	5.6
1975	—	7	13	42	1	19	—	2	—	—	—	—	—	1	14	71	5.1
Total	26	136	186	529	99	370	9	95	3	16	1	2	—	2	324	1,150	3.5
Sex ratio(F/M)	5.2		2.8		3.7		10.6		5.3		2.0		—		3.5		

age IV in Lake Francis Case, but Walburg (1964) reported fish up to age VI in Lewis and Clark Lake. In the Little Missouri Arm of Lake Sakakawea, Wahtola et al. (1971) noted that yellow perch seldom exceeded age IV. Yellow perch in Missouri River reservoirs thus seemed to be shorter-lived than those in other localities of the North Temperate Zone of North America, such as Saginaw Bay (Eshenroder 1977), West Blue Lake, Manitoba (Kelso and Ward 1977), and the Red Lakes, Minnesota (Smith 1977).

Relative strengths of the 1964-72 year classes were estimated from the mean catch per summer gill-net set of combined ages I-III of each year class. The 1964 year class was unusually strong and dominated the catches in 3 successive years (1965-67). The mean C/f for yellow perch of that year class was nearly twice that of the 1965 and 1966 year classes and 10 times that of the 1967-71 year classes, as shown by the following mean C/f at ages I-III (combined):

Year class									
1964	1965	1966	1967	1968	1969	1970	1971	1972	
3.3	1.7	1.9	0.3	0.4	0.3	0.3	0.4	1.0	

Variability in year-class strength during 1967-75, as judged by catches of YOY, may be

After a 5-year series of weak year classes, the 1972 year class appeared to be moderately stronger, partly attributable to differences in the relative size of the brood stock producing each year class. A strong positive relation was indicated between the mean C/f of sexually mature yellow perch by gill nets during summer and the mean C/f of YOY by seines in the following summer ( $r = 0.96$ ;  $P < 0.01$ ; Fig. 4). A similar relation was apparent for catches in the trawl ( $r = 0.75$ ;  $P < 0.05$ ). The above-average abundance of YOY fish in 1967 probably resulted from fish produced by the very strong 1964 year class. The strongest year class (as YOY) was produced in 1968 by adults from primarily the 1964 and 1965 year classes. Additionally, a moderately strong year class in 1969 was largely the progeny of the relatively strong 1966 year class. Year classes were of below-average strength from 1970 to 1975, when brood stocks had become reduced.

Although, as shown earlier, there was a significant correlation between the C/f of YOY fish with seine and trawl, these measures were not indicative of relative year-class strength as deduced from gill-net catches. For example, the mean C/f of YOY in 1968 with seine and trawl (151 and 153 fish, respectively) was the highest recorded during 1967-75; however, no yearling fish of this year class were caught in 1969, and the mean C/f of ages I-III combined was only 0.4. It thus appears that overwinter mortality was sufficiently high to

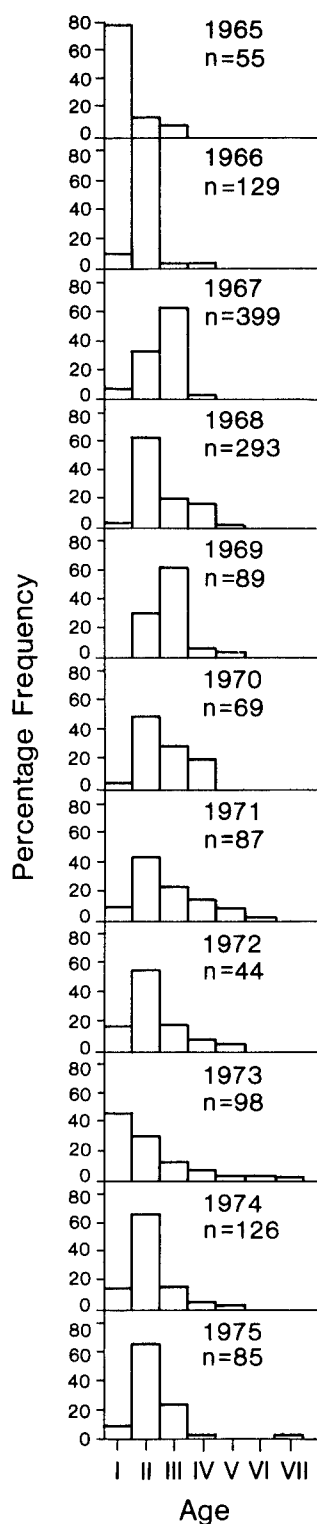


Fig. 3. Age composition of yellow perch in summer (June-September), based on gill-net catches in six localities in Lake Sharpe, 1965-75.

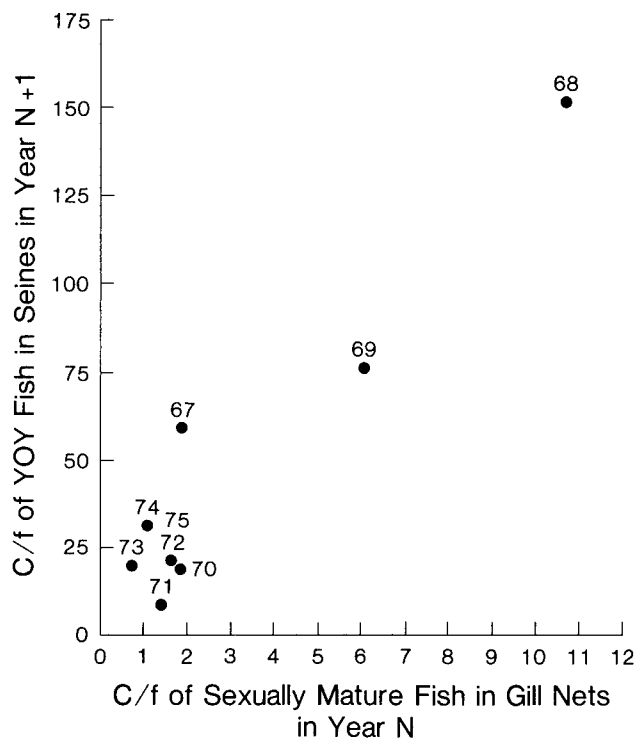


Fig. 4. Relation between the mean catch of young-of-the-year yellow perch by seine and the mean catch of sexually mature adults by gill nets in the previous summer, 1967-75.

negate any relation between abundance of YOY and their subsequent recruitment to the adult stock.

### *Recruitment and Survival*

Yellow perch were first taken by gill nets at age I, but were probably not fully vulnerable to capture until age III (Fig. 5). The oldest fish in the catches were two age-VII females (Fig. 3). In general, however, adults were relatively short-lived, males seldom exceeding age III or females age IV. Females not only had a higher average survival rate for ages III-VI (0.196) than males (0.115), but also had a longer life span.

### *Sex Ratio*

The overall mean ratio of female to male yellow perch in summer gill-net catches was 3.5 to 1. Females outnumbered males in every year (Table 7), although the ratios varied greatly (from

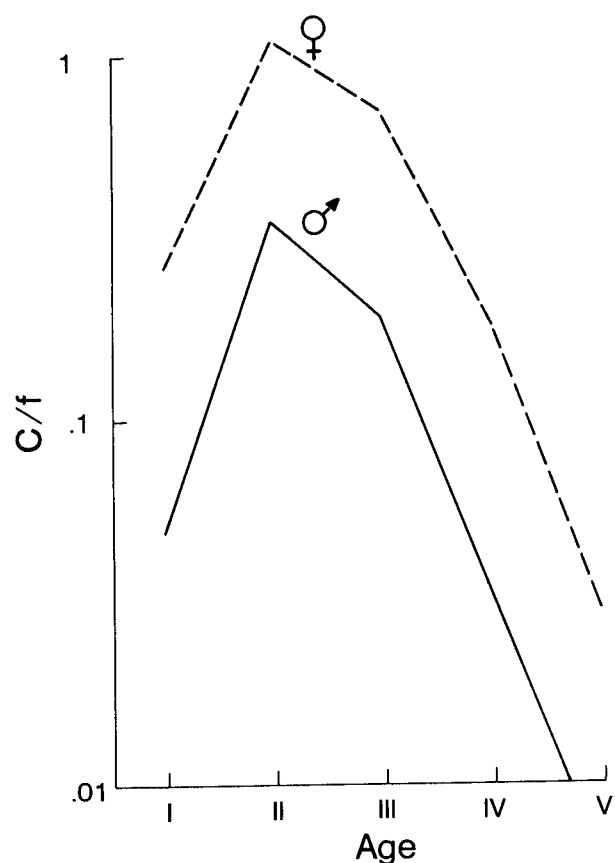


Fig. 5. Mean catch rates for male and female yellow perch of different ages in gill nets, Lake Sharpe, 1964-75.

1.7 to 1 in 1966 to 22 to 1 in 1970). Sex ratios were lowest during 1965-67 (roughly 2 to 1). The proportion of females increased substantially through 1970, remained high through 1973, and decreased thereafter.

Females outnumbered males in every age group (Table 7). At age I, females exceeded males by an average factor of 5.2, due mainly to a difference in size at recruitment to the gill nets. At age II the sexes were more closely matched (2.8 to 1) than at any other age represented by reasonably adequate samples. By age III, a lower survival rate among males decreased their relative numbers, and by age IV the females outnumbered males 10.6 to 1. Females continued to outnumber males at older ages.

## Growth

There were no significant differences in the mean lengths of adult yellow perch from various localities of the reservoir; data on growth were therefore combined. Annual growth of adults was variable, and no trend was apparent for year classes 1961-74 (Table 8). Calculated lengths of males and females were not significantly different at ages I and II. Comparisons could not be made for older age groups, due to a scarcity of males.

Growth of yellow perch in Lake Sharpe was slower than in Lake Francis Case but faster than in Lakes Oahe and Sakakawea (Table 9). Comparison of yellow perch growth as determined in this study with that in waters outside the Missouri River basin suggested that growth was generally slower in Lake Sharpe.

## Sexual Maturation and Spawning

Female yellow perch matured at an older age and at a larger size than males. No yearling females were sexually mature. The smallest sexually mature females were four age-II fish 130 mm long; three other mature age-II females were 133 mm long. Most males were sexually mature at age I. The smallest sexually mature (ripe) yearling male was 54 mm long, and five others were 60 to 69 mm long. Additionally, hundreds of ripe age-I males of the 1966 year class, 75 to 107 mm long, were taken during the 1967 spawning season. Adrian (1972) reported that female yellow perch in Lake Oahe first became sexually mature at 140 mm and that 27% of the fish of age II were mature; all were mature at a length of 171 mm or longer and an age of III or older. He found no sexually mature yearling males, but all age-II and older males were mature, and the two smallest sexually mature males were 138 mm long. Thus yellow perch appeared to attain sexual maturity at a smaller size and younger age in Lake Sharpe than in Lake Oahe.

The semimonthly mean ovary indices (percent-age of total weight of fish contributed by ovaries) during 1964-75 indicated that maturation of the ova for the seasonal spawning of yellow perch in Lake Sharpe began by mid-September (Fig. 6), and that spawning took place between mid-April and

Table 8. *Calculated total lengths of yellow perch at end of each year of life, Lake Sharpe, 1964-75 (number of fish in parentheses).*

Year class and sex	Average length (mm) at end of year						
	1	2	3	4	5	6	7
1974							
Female	82 (9)						
Male	—						
1973							
Female	78 (50)	136 (46)					
Male	79 (14)	131 (13)					
1972							
Female	84 (96)	138 (49)	181 (19)				
Male	86 (13)	143 (10)	182 (1)				
1971							
Female	80 (41)	141 (35)	184 (8)	207 (2)			
Male	81 (8)	135 (6)	170 (1)				
1970							
Female	76 (58)	138 (41)	183 (15)	199 (2)			
Male	74 (9)	125 (6)	155 (1)				
1969							
Female	72 (52)	131 (49)	163 (16)	202 (8)	208 (2)		
Male	69 (4)	129 (4)					
1968							
Female	72 (60)	122 (59)	159 (25)	180 (6)	184 (3)	197 (1)	209 (1)
Male	73 (5)	119 (5)	164 (2)				
1967							
Female	72 (65)	109 (65)	146 (35)	167 (15)	201 (3)	214 (1)	
Male	78 (11)	114 (10)	166 (3)	197 (2)	242 (1)	255 (1)	
1966							
Female	82 (244)	127 (225)	146 (71)	170 (20)	193 (7)	214 (1)	230 (1)
Male	80 (50)	123 (45)	141 (9)	161 (3)	158 (2)		
1965							
Female	78 (133)	125 (124)	162 (59)	178 (6)	174 (1)	185 (1)	
Male	80 (85)	129 (80)	162 (10)				
1964							
Female	72 (362)	128 (331)	156 (246)	183 (53)	213 (3)		
Male	75 (164)	131 (152)	151 (95)	176 (8)			
1963							
Female	75 (15)	149 (11)	169 (6)	194 (3)			
Male	67 (8)	166 (6)					
1962							
Female	79 (92)	124 (92)	178 (7)	209 (3)			
Male	78 (18)	117 (18)	178 (6)				
1961							
Female	85 (23)	138 (23)	164 (23)	220 (1)			
Male	85 (2)	127 (2)	156 (2)				
Unweighted average length							
Female	77	131	166	192	196	202	220
Male	77	130	162	178	200	255	
Combined	77	131	166	192	196	208	220

Table 9. *Calculated total length at each annulus for yellow perch, sexes combined, from four Missouri River reservoirs and three waters outside the Missouri River basin.*

Location	Average length (mm) at each annulus						Source
	I	II	III	IV	V	VI	
Lake Sharpe	77	131	166	192	196	208	Present study
Lake Francis Case	84	148	190	216			Gasaway (1970)
	65	147	183	205			Walburg (1977)
Lake Oahe	72	122	159	182	203	216	Asafo (1970)
Lake Sakakawea	81	126	155	181			Wahtola et al. (1971)
Red Lakes, Minnesota	74	132	173	201	221	234	Smith (1977)
Saginaw Bay, Michigan	81	138	172	196	218	223	Eshenroder (1977)
Severn River, Maryland	108	166	202	230	253	271	Muncy (1962)

mid-May. In 1967, the first ripe female was found on 19 April and the first fully spent female on 26 April; the last ripe female was taken on 12 May. Thus, spawning in that year probably lasted about 24 days. Mean peak spawning during 1965-75 occurred within an 11-day period (29 April-8 May), and the estimated grand-mean date for peak spawning was 2 May. Water temperatures during spawning ranged from 8.9 to 11.8°C. Dates and water temperatures during spawning of yellow perch in Lake Sharpe were similar to those reported by June (1977) in Lake Oahe.

Yellow perch spawned on inundated grasses, weeds, shrubs, and aquatic macrophytes in the shallow, protected waters of most of the major tributary embayments of Lake Sharpe and in Hipple Lake. An influx of sexually mature males and

females into these areas generally began several weeks before active spawning began, and some of the males were ripe at that time. Within a week or so after the occurrence of the last ripe females, the fish left the spawning grounds.

## Discussion

The stocks of YOY and adult yellow perch declined in Lake Sharpe during the 1970's. The average abundance of YOY during 1970-75 decreased from that during 1967-69 by about 80% in both the seine and trawl catches, and the average abundance of adults dropped by about the same percentage.

The marked decline in abundance of YOY yellow perch beginning in 1969 appears to have been largely the result of a general degradation of the spawning and nursery areas in the reservoir. During the first several years of impoundment, newly inundated terrestrial vegetation provided extensive substrate for egg deposition during spawning. However, herbaceous vegetation soon disappeared, and within the first five postimpoundment years (1964-68), erosion and sedimentation not only destroyed much of the remaining woody vegetation, but also greatly reduced the volume of most embayments, particularly those along the west bank (Benson 1980; June 1987). The presence of aquatic vegetation in protected areas of the reservoir seemed to be primarily responsible for sustaining yellow perch reproduction.

This explanation of the decrease in the YOY of yellow perch stock in Lake Sharpe is consistent with the observations of June (1976) concerning changes in the YOY yellow perch stock in Lake

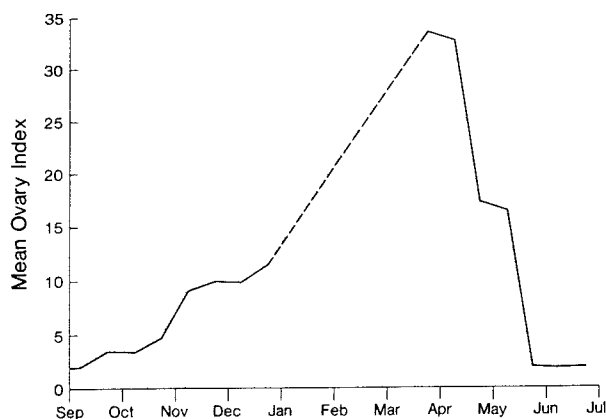


Fig. 6. Mean ovary indices (percentage of total weight of fish contributed by ovaries) of yellow perch, by semi-monthly periods, Lake Sharpe, 1964-75 (broken line indicates no data).

Oahe, and is also supported by the association of increased abundance of YOY yellow perch with reinundation of terrestrial vegetation in Lake Francis Case (Gasaway 1970). Our work also suggested that abundance of YOY yellow perch was positively related to the size of the spawning stock. Water regimen, weather, or the abundance of other fishes undoubtedly influenced each year's production of YOY yellow perch, but quality of the spawning and nursery areas and size of the brood stock were probably the most important factors governing annual spawning success.

These conclusions suggest that the reproductive success of yellow perch in Lake Sharpe could be enhanced by the introduction of trees or brush to provide additional spawning substrate in suitable locations. Echo (1955), for example, observed that most yellow perch eggs were deposited on submerged conifers in Thompson Lakes (Montana), and W. R. Nelson (personal communication) observed that discarded Christmas trees were heavily used by spawning yellow perch in trials made in a number of embayments in Lake Oahe. Because water levels in Lake Sharpe are relatively stable, introductions of aquatic macrophytes might also be successful, and provide suitable spawning substrate. The addition of spawning substrate in protected waters of the principal embayments could be expected to increase reproduction of yellow perch in Lake Sharpe, and thus help strengthen the forage base for predatory fishes in the reservoir.

## Acknowledgments

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# Early Life History and Winter Mortality of Gizzard Shad in Lake Sharpe, South Dakota

by

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## Abstract

This study of gizzard shad (*Dorosoma cepedianum*) was conducted from 1967 to 1975 in Lake Sharpe, a 22,600-ha reservoir in central South Dakota. The impoundment is at the northern limit of distribution of the species in the main-stem Missouri River impoundment system. The gizzard shad of Lake Sharpe is not morphologically distinct from populations inhabiting other inland waters. Young of the year generally spent the summer in tributary embayments, were most abundant in midreservoir localities, and apparently moved upstream in fall in response to inflow of warm water from Lake Oahe. During 1967-75, gizzard shad composed 56% of the total catch of young of the year in seines and 40% of that in trawls. Seine catches were highest in 1968, decreased annually through 1972, rose sharply in 1973, and declined again in 1974-75. Growth rates of young of the year, and mean lengths attained, varied during the 9-year period, but no trend with time was detected. Summer mortality was relatively low; however, over-winter mortality of the young of the year was seemingly complete in every year except 1967. Low water temperature in winter was judged to be the primary factor limiting the gizzard shad population in Lake Sharpe.

The gizzard shad (*Dorosoma cepedianum*) frequents estuaries, rivers, backwaters, large open lakes, and reservoirs. It occurs only on the North American continent, where its coastal distribution extends from Cape Cod to central Mexico and its inland distribution from the St. Lawrence River westward to eastern Wyoming and southward to the Gulf of Mexico (Miller 1960; Baxter and Simon 1970).

The first record of its occurrence in the Missouri River drainage was that reported by Jordan and Meek (1885), who collected it at St. Joseph, Missouri, in 1884. Its occurrence in South Dakota was first reported by Meek (1892), based on collections made in the Missouri and Big Sioux rivers at Sioux City, Iowa, in 1889 and 1890. There was no further confirmed report of gizzard shad in the upper Missouri River until after dam construction had

begun in South Dakota in the early 1950's. (See Fig. 1 for location of South Dakota reservoirs.) Carufel and Witt (1963) reported the capture of one specimen in the Missouri River below Garrison Dam, about 95 km upstream from Bismarck, North Dakota. This capture was made before the closure of Oahe Dam near Pierre, South Dakota, in 1958. Walburg (1964) reported a sustaining population in Lewis and Clark Lake after closure of Gavin's Point Dam in 1955; young of the year (YOY) were taken in every subsequent year, and until 1967 the gizzard shad was one of the more abundant species in seine and trawl catches. Thereafter the catches of both YOY and adults in this reservoir declined noticeably (Walburg 1976). Gasaway (1970) reported that the gizzard shad was the most abundant species in 1954-55 collections of YOY from Lake Francis Case (Fort Randall Reservoir), but that its numbers were greatly reduced after 1958; no adult gizzard shad

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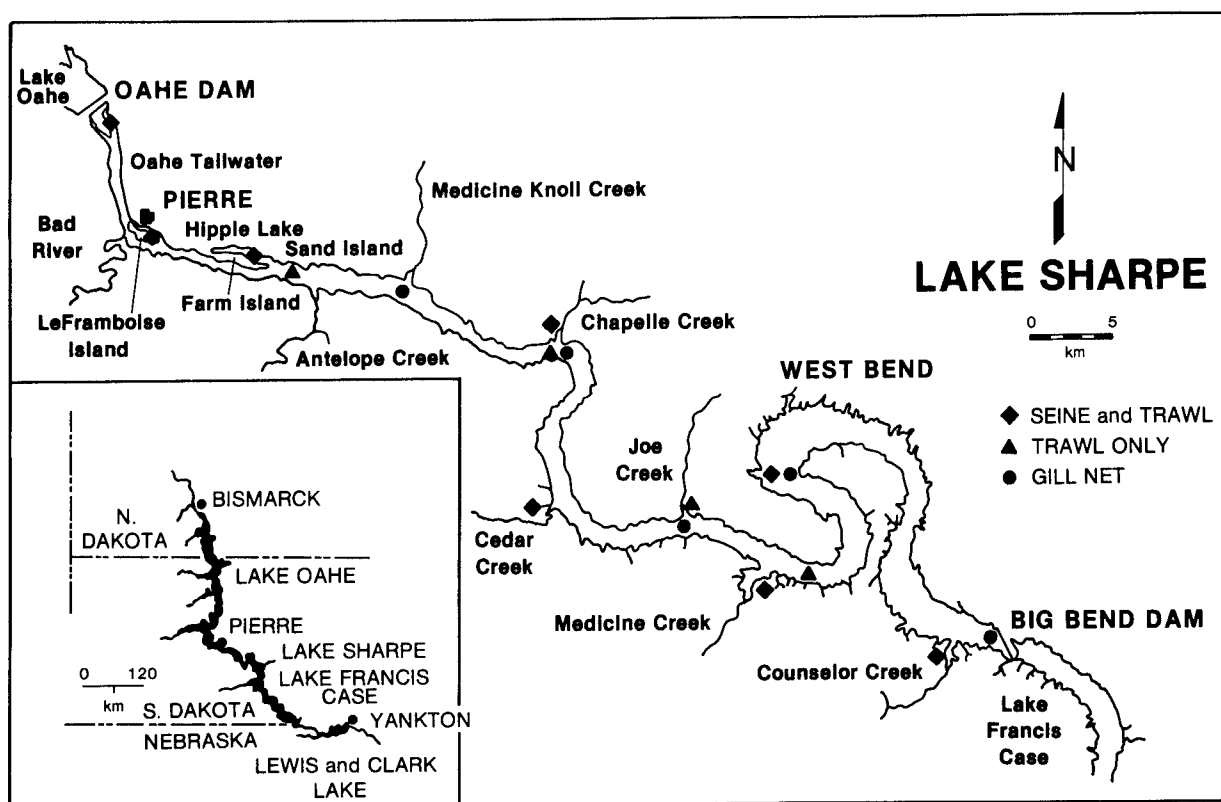


Fig. 1. Fish-sampling locations in Lake Sharpe, 1967-75.

Table 1. Some morphometric measurements (mm) and meristic counts of juvenile gizzard shad from Lake Sharpe ( $n = 50$ ).

Measurement	Range (mm)	Count	Range	Mean	SD
Standard length	69-96	Dorsal rays	13-16	13.96	0.67
Fork length	76-107	Anal rays	26-38	32.62	2.09
Total length	88-123	Pectoral rays	14-17	15.59	0.76
Body depth	24-38	Pelvic rays	7-8	7.92	0.27
Body depth	2.4-2.9	Vertebrae	49-51	49.98	0.65
in standard length		(including urostyle)			
Head length	22-29	Ventral scutes (total)	28-32	29.86	0.76
Head length	3.0-3.6	Prepelvic scutes	17-19	18.06	0.37
in standard length					
Predorsal length	37-48	Postpelvic scutes	11-14	11.80	0.64
Predorsal length	1.9-2.2				
in standard length					
Preanal length	48-65				
Preanal length	1.4-1.6				
in standard length					

were taken in 1967 gill-net samples, although YOY were taken in seines in 1966-68. The gizzard shad was by far the most abundant species in catches of YOY in Lake Sharpe during 1967-75 (Beckman 1987). Extensive seine collections in 1964-74 failed to produce any specimens in Lake Oahe (Beckman and Elrod 1971; June 1976), and none have been reported in Lakes Sakakawea or Fort Peck. Thus Lake Sharpe is almost certainly the northern limit of distribution of the gizzard shad in the present-day Missouri River reservoir system. Further penetration of this species into the upper Missouri River was doubtless limited by temperature (Miller 1957).

This report is based on fish sampling conducted in 1967-75 by the North Central Reservoir Inves-

tigations (Beckman 1987) in Lake Sharpe, a 22,600-ha reservoir in central South Dakota. I describe the taxonomy, distribution, abundance, growth, and mortality of gizzard shad—an important forage fish for predators, such as the walleye (*Stizostedion vitreum vitreum*), during the early years of impoundment of Lake Sharpe (Elrod et al. 1987).

## Taxonomy

Morphometric measurements and meristic counts (Table 1) conform to classical descriptions of the species. Gizzard shad in Lake Sharpe have

Table 2. Catches of young-of-the-year gizzard shad per seine haul and per trawl haul in various localities of Lake Sharpe, 1967-75. See Beckman (1987) for details of sampling program.

Gear and locality	1967	1968	1969	1970	1971	1972	1973	1974	1975	Mean
Seine										
Embayment										
Counselor Creek	1	30	2	8	40	24	29	28	14	20
Medicine Creek	32	60	219	82	45	64	47	102	49	78
Cedar Creek	109	109	42	150	39	116	233	64	23	98
Hipple Lake	87	1,187	952	542	525	64	126	72	166	413
LeFramboise Island	53	24	12	25	3	4	140	216	38	57
Floodplain										
West Bend	1	3	7	22	5	12	21	3	4	9
Chapelle Creek	68	89	169	114	163	32	134	39	119	103
Channel										
Oahe tailwater	1	4	1	2	2	7	2	4	0	2
Mean	44	188	175	118	103	40	92	66	52	98
Trawl										
Embayment										
Counselor Creek	0	1	10	16	27	1	1	2	<1	6
Medicine Creek	28	47	193	20	13	50	23	316	25	79
Cedar Creek	89	43	16	71	51	95	31	34	76	56
Hipple Lake	21	974	426	399	63	173	215	301	241	313
LeFramboise Island	228	15	9	30	68	30	6	14	2	45
Floodplain										
West Bend	2	51	13	79	67	3	6	22	10	28
Joe Creek	11	27	7	19	7	5	3	91	48	24
Chapelle Creek	1	3	12	5	7	3	19	44	9	11
Channel										
Medicine Creek	0	0	0	0	0	0	<1	0	0	<1
Chapelle Creek	0	0	<1	0	0	0	<1	<1	<1	<1
Sand Island	1	2	6	4	<1	1	2	3	4	3
Oahe tailwater	1	0	0	10	0	0	0	0	<1	1
Mean	32	97	58	54	25	30	26	69	35	47

higher mean numbers of dorsal and anal rays, ventral scutes, and vertebrae, and slightly greater body depth than reported by Miller (1960). Differences are not sufficiently great, however, to consider gizzard shad from Lake Sharpe a distinct form. Hubbs and Whitlock (1929) recognized the gizzard shad as a plastic species, and believed that morphological variations in young fish resulted from environmental influences. Variations in water temperature probably cause latitudinal variations in meristic numbers, and the higher counts for fish from more northerly (i.e., cooler) Lake Sharpe waters seem to follow "Jordan's Law 2" (Gray 1967).

## Distribution and Abundance

The YOY gizzard shad in Lake Sharpe were in compact schools soon after hatching and were generally in tributary embayments through most of the summer. Few fish were taken in limnetic waters of embayment channels. Catches were generally highest in Hipple Lake and lowest in upstream and downstream localities (Table 2; Fig. 1). In late summer, schools seemed to increase in size, and as the water temperature declined toward 14°C, most YOY moved out of the shallower tributary embayments into the deeper waters of the reservoir. These fish apparently moved upstream in response to the warmer inflow from Lake Oahe (June 1987); YOY usually appeared in Lake Oahe tailwater in mid or late September, and some were

taken by seine or gill net almost every fall (Table 3).

The gizzard shad was the most abundant YOY fish in seine and trawl catches in nearly every year of the 1964-75 study (Beckman 1987). It was out-ranked in the seine catches by yellow perch (*Perca flavescens*) in 1967, and in the trawl catches by yellow perch in 1967, 1968, and 1973 and by black crappies (*Pomoxis nigromaculatus*) in 1970 and 1973. Gizzard shad accounted for 56% of the YOY caught in seines and 40% of those caught in trawls in 1967-75.

Seines were generally more effective than trawls for collecting YOY gizzard shad (Table 2). Seine catches peaked in 1968, declined annually through 1972, rose sharply in 1973, and decreased thereafter. Trawl catches dropped noticeably from 1968 to 1971 and remained relatively stable thereafter, except for an increase in 1974. Although the overall mean catch with seines was double that with trawls, mean seine and trawl catches for different years and localities were well correlated ( $r = 0.67$ ;  $P < 0.05$ ; and  $r = 0.96$ ;  $P < 0.01$ , respectively). Annual mean rates of decrease during 1968-75 for both gears were about the same (10% and 9%). Thus the decline in abundance of YOY gizzard shad was probably real.

No significant correlation was found between the seasonal abundance estimates and any of the biological or environmental variables investigated (abundance of zooplankton and phytoplankton, abundance of YOY and adults of other fish species, water temperature, and discharge rate).

Table 3. Mean monthly catches of young-of-the-year gizzard shad per seine haul and per gill-net set in Oahe tailwater, Lake Sharpe, 1967-75.

Gear and month	1967	1968	1969	1970	1971	1972	1973	1974	1975
<b>Seine</b>									
July	0	0	0	1	0	0	0	0	0
August	0	10	1	1	0	<1	0	1	0
September	2	0	0	7	14	39	11	24	0
<b>Gill net</b>									
July	0	0	0	0	0	0	0	0	0
August	0	0	1	0	0	0	0	0	0
September	0	0	10	<1	2	2	1	1	0
October	0	0	13	<1	4	1	<1	<1	<1
November	25	0	8	0	0	0	0	0	<1
December	58	0	<1	0	0	0	0	2	0

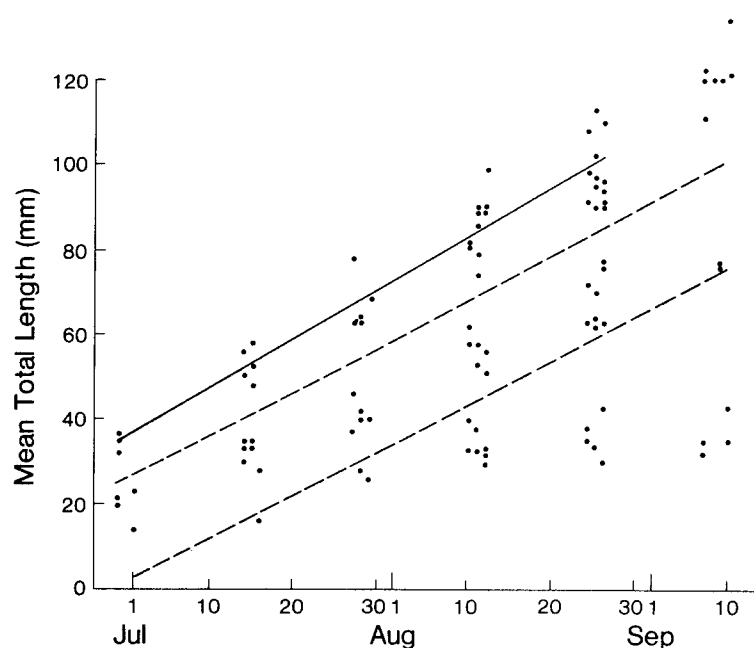


Fig. 2. Mean lengths of young-of-the-year gizzard shad in seine and trawl samples, according to date of capture, Lake Sharpe, 1970. The upper solid line is the least-squares regression of mean lengths of the cohorts that hatched earliest. The dashed lines include a second group of cohorts that hatched later. Several additional cohorts are evident below the lower dashed line.

## Growth

Spawning of gizzard shad in Lake Sharpe extended from June to September. Spawning and hatching were intermittent in the various localities. Because the spawning season was protracted, seine and trawl catches usually contained a mixture of YOY of different sizes and ages.

A sample of 50 fish (when available) from each seine and trawl catch was preserved in 5% formalin. Fork lengths (mm) of the fish plotted as length-frequency distributions showed the presence of one or more size groups, presumably reflecting different hatches. Homologous length groups were easily separated by inspection, and the mean of each group was calculated. The means of homologous length groups in samples from all localities (Fig. 2) showed a linear relation with time in all instances. Accordingly, least-square regressions of the mean lengths of the earliest-hatched cohort on coded dates were calculated for each year. Growth rate during 1 July–1 September and the attained length on 23 August were estimated from the regressions. On the basis of measurements of both fork and total lengths of 100 fish over the fork length range of 9–133 mm, I converted fork lengths to total lengths (which are used in the present report) by the equation, total length (mm) =  $-1.435 + 1.167$  fork length (mm).

Growth of young gizzard shad was rapid, averaging about 1 mm per day from 1 July to 1 September. Growth estimates are probably conservative because the larger, older fish probably avoided the sampling gears. The instantaneous rates during 1967–75 ranged from 0.92 in 1974 to 1.38 in 1971 (Table 4). Although growth varied from year

Table 4. Mean instantaneous growth rates in length (1 July–1 September) and calculated mean total length (mm) on 23 August of young-of-the-year gizzard shad in Lake Sharpe, 1967–75. (Estimates were based on the cohort that hatched earliest in each year.)

Year	Growth rate (mm/day)	Calculated total length 23 August (mm)
1967	1.17	92
1968	1.19	96
1969	1.33	88
1970	0.98	98
1971	1.38	107
1972	0.99	88
1973	1.06	80
1974	0.92	77
1975	1.11	103

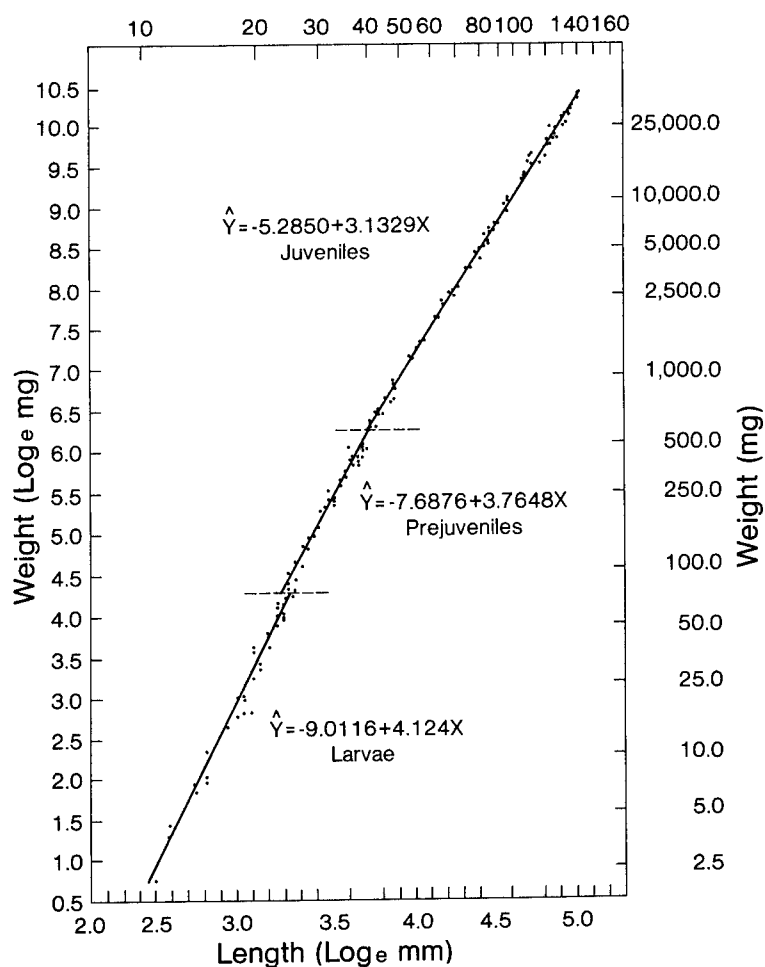


Fig. 3. Regressions of weight on length of gizzard shad, Lake Sharpe: larvae (< 25 mm long), prejuveniles (25-40 mm), and juveniles (> 40 mm).

to year, no trend was evident. No significant relation was found between the growth rates or the attained lengths on 23 August and any of the biological or environmental variables examined (abundance of YOY gizzard shad; abundance of phytoplankton and zooplankton; and water temperature, level, turbidity, and discharge rate). Weak inverse relations (not statistically significant) existed between the attained length on 23 August and water temperature, abundance of YOY gizzard shad, and abundance of cladocerans; however, about 30% of the observed year-to-year variability in length attained on 23 August might be explained by these three variables. These results suggest that growth in length of YOY giz-

zard shad was governed by many interacting factors, none of which appear to have been limiting under ecological conditions existing in Lake Sharpe during 1967-75.

Mean lengths of YOY male and female gizzard shad in fall gill-net catches in Oahe tailwater were not significantly different. Sex ratios in these samples ranged from 0.93 to 1.46 males per female (average, 1.14).

The length-weight relation of fish 12 to 152 mm long indicated three distinct stages in the development of young gizzard shad (Fig. 3). Fish less than 25 mm long and weighing less than 72 mg were classified as larvae. They were elongated and slender and were generally devoid of pigmentation

except for several large chromatophores anterior to the anus and two longitudinal rows of chromatophores along the dorsal wall of the anterior third of the alimentary tract. At lengths of about 25–40 mm and weights of 72–450 mg, the fish were intermediate between larval and juvenile forms. The body had begun to increase in depth, the adult fin-ray complement had been attained by most of the fish, pigmentation had increased, and the adult body form had become recognizable. Specimens exceeding 40 mm in length and 450 mg in weight were classified as juveniles. Fish at this stage had their full complement of meristic characters and had the body form and pigmentation of adults. No sexual difference in the length-weight relation of juveniles was evident.

## Mortality

Instantaneous mortality rates ( $Z$ ) of YOY gizzard shad during 1967–75 were estimated from regressions of the natural logarithms of the catch per seine haul of the earliest-hatched cohort in Hipple Lake on coded dates during the period 15 July–1 September. Calculated rates of decline during this period included the combined results of mortality and emigration of larger fish, and thus were probably biased upward.

Mortality rates were highly variable, but there was a downward trend after 1969 (Table 5). No significant relation was found between the instan-

taneous mortality rates and water discharge, water level, turbidity, and abundance of yellow perch; however, there was a significant inverse relation between mortality rates and mean water temperature ( $r = -0.79$  and  $P < 0.01$ ), abundance of YOY gizzard shad ( $r = -0.92$  and  $P < 0.01$ , and  $r = -0.62$  and  $P < 0.05$  for seine and trawl catches, respectively), and abundance of YOY walleyes (*Stizostedion vitreum vitreum*) as estimated by seine catches ( $r = -0.71$  and  $P < 0.05$ ) reported by Beckman (1987). Multiple regression analysis incorporating these three variables gave an  $R$  value of 0.96 ( $P < 0.01$ ). Thus the mortality of YOY gizzard shad in this locality of Lake Sharpe seemed to increase at the lower summer water temperatures and at the lower densities of both YOY gizzard shad and YOY walleyes.

Mass mortalities of YOY gizzard shad, during each winter of 1967–75 were associated with low water temperatures, and were commonly observed in the relatively quiet water areas of Oahe tailwater and in the vicinity of LeFramboise Island. When the water temperature fell below about 2.0°C (usually in February), the fish scattered, lost equilibrium, and swam erratically (often on their side) or sank toward the bottom. During such times, thousands of dead or moribund shad could be seen lying on the bottom. Such mortalities usually annihilated the YOY stock in Lake Sharpe. Gill-net catches of gizzard shad during 1964–75, tabulated by age group, clearly illustrate the effects of this mortality (Table 6). After 1965, the only known overwinter survival of young gizzard shad occurred during the winter of 1966–67, when daily water temperatures during February averaged 1.0 to 1.6 Celsius degrees higher than in other years.

Because of the advanced age of the 1966 year class by the mid-1970's and the absence of any younger fish, the spawning stock of gizzard shad was greatly reduced, and this reduction was accompanied by a decline in YOY. Survival of the population of gizzard shad in Lake Sharpe appeared to be tenuous, and its extinction possibly imminent.

## Discussion

Although the abundance of gizzard shad in Lake Sharpe declined after 1968, the fish continued to dominate the seine catches of YOY fish through

Table 5. *Instantaneous mortality rates (15 July–1 September) of young-of-the-year gizzard shad in Hipple Lake, Lake Sharpe, 1967–75. (Estimates were based on the cohort that hatched earliest each year.)*

Year	Mortality rate
1967	0.045
1968	0.113
1969	0.137
1970	0.068
1971	0.087
1972	0.020
1973	0.042
1974	0.047
1975	0.029

Table 6. Numbers of gizzard shad of different ages taken with gill nets in Lake Sharpe, 1964-75 (units of effort shown in parentheses).

Age group <sup>a</sup>	Collection year and effort											
	1964 (13)	1965 (63)	1966 (83)	1967 (53)	1968 (65)	1969 (63)	1970 (59)	1971 (61)	1972 (60)	1973 (63)	1974 (60)	1975 (60)
0	407	1	271	7	3	74	23	18	26	17	18	18
I	5	0	0	80	0	0	0	0	0	0	0	0
II	0	0	0	0	3	0	0	0	0	0	0	0
III	2	0	0	0	0	2	0	0	0	0	0	0
IV	0	0	0	0	0	0	6	0	0	0	0	0
V	0	0	0	0	0	0	0	3	0	0	0	0
VII	0	0	0	0	0	0	0	0	0	12	0	0
VIII	0	0	0	0	0	0	0	0	0	0	1	0

<sup>a</sup>No fish of age VI were collected.

1975. Overwinter survival of YOY during 1967-75 was apparently nil, although summer survival was judged to be relatively high. Few adults were taken in gill nets in any year, and the 1966 year class was the only one represented after 1965. Growth of YOY was rapid, and varied little from year to year, despite differing densities of fish. This lack of variation with density suggests that the plankton on which the gizzard shad feeds (Kutkuhn 1958a; Bodola 1966) was adequate. I conclude that winter water temperature was the critical factor regulating the gizzard shad population in Lake Sharpe. Walburg (1964) came to a similar conclusion from studies of Lewis and Clark Lake; he found no apparent overwinter survival of YOY gizzard shad in years when reservoir ice cover exceeded 103 days.

Young gizzard shad form an important link between plankton and predatory fishes (Lagler and Applegate 1943; Kutkuhn 1955, 1958b). Their disappearance from Lake Sharpe would doubtless have depressing effects on the density and well-being of predatory fishes—particularly the walleye.

Unless there is some overwinter survival of young, the gizzard shad in Lake Sharpe is destined for extinction. If that occurs, I recommend that an adult stock be reestablished and that stocking priority be given to Hipple Lake, the most productive spawning and nursery locality for this species in Lake Sharpe. The stocking of yearling or older gizzard shad from any of the downstream reservoirs (still near the northern range of the species),

might improve the possibility of establishing a self-sustaining population in Lake Sharpe.

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